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Impact of Cotton Seed Treatments and Preemergence Herbicides on Thrips Infestations

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By

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Impact of cotton seed treatments and preemergence herbicides on thrips infestations

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Research was conducted in 2013 and 2014 to evaluate the influence of cotton (*Gossypium hirsutum* L.) insecticidal seed treatments, planting date, and preemergence herbicides on thrips (*Frankliniella fusca*) infestations in cotton. Studies included a preemergence and soil texture evaluation on cotton development, an evaluation of thrips infestations, cotton development and yield following application of various preemergence herbicides and insecticidal seed treatments, and a planting date evaluation where different cultivars where planted with exclusion or inclusion of preemergence herbicide use at four different planting dates to determine the effect on thrips infestations, cotton development, and yield.

DEDICATION

I would like to dedicate this research to my friends and family for the continuous support during this process, more specifically my mother, Wendy Thompson, Grandmother, Judy Winchester and fiancée Kasey Elswick. Throughout my life you have provided love and support that cannot be explained. I appreciate all that you have done for me. I would also like to dedicate this research to all the mentors who provided me with direction and experience that stimulated my interest in agriculture.

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CHAPTER I

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) was the main cash crop throughout the Cotton Belt in the 19th and most of the 20th century (Anonymous 2013). Cotton production in this region has become less dominant as production of corn, wheat, and soybean has largely replaced cotton (Anonymous 2013). In the U.S., 18.8 million hectares of cotton were harvested in 2013 totaling approximately $5.2 trillion in production (USDA/NASS 2014). Mississippi was the fifth largest cotton-producing state behind Texas, Georgia, North Carolina, and Arkansas, respectively, in 2012 (USDA/NASS 2014). Cotton production in 2013 totaled approximately 730,000 bales on 703,950 harvested hectares in Mississippi (USDA/NASS 2014).

Cotton grows as a perennial shrub that requires warmer temperatures for optimum growth; however, cotton is grown commercially as an annual shrub (Chaudhry and Guitchounts 2003). Of the five different types of cotton species, the Acala type is an upland cotton originally selected from germplasm introduced from Mexico to the USA (Chaudhry and Guitchounts 2003). For successful germination of cotton seed, soil temperatures must be at least 15.5°C and at least 50 to 60 heat units are required for the seedling to emerge (Chaudhry and Guitchounts 2003). Optimum temperature for cotton growth and development is from 20 to 30°C (Reddy et al. 1991).The basic formula for calculating a heat unit is as follows: add the maximum and minimum daily temperature, divide by 2, and subtract the threshold temperature (20°C) (Chaudhry and Guitchounts 2003).

$$[(\text{Maximum temperature } (^{o}F) + \text{Minimum temperature in } (^{o}F)/ 2] - 60 = \text{Degree Days} \qquad 1.1$$

After the cotyledons unfold, first true leaves develop in 7-14 days (Main 2012). Emergence of the second true leaf until pinhead square (seventh to ninth node) generally takes an additional 18 to 21 days (Chaudhry and Guitchounts 2003). The first developing true leaves are vital to proper plant development and need protection from insects for optimum development of a deep, healthy root system (Main 2012).

The two types of branches on a cotton plant are classified as monopodial (vegetative) and sympodial (reproductive) branches (Ritchie et al., 2008). Vegetative branches contain one meristem and have a straight, erect growth habit and can also produce fruiting branches (Ritchie et al., 2008). Fruiting branches arise on the main-stem around the 5^{th} or 6^{th} node, meaning vegetative branches generally develop from the 4^{th} node down (Ritchie et al., 2008).

Cotton has an indeterminate growth habit and can produce rank growth under the right conditions. Rank growth can be caused by excessive fertilizer application and fertile soils (Gerik et al. 1998; Chaudhry and Guitchounts 2003). Considering the growth habit of cotton, plant growth regulators are used commonly to suppress vegetative growth (Reddy et al. 1990). Excessive vegetative growth can result in boll rot and fruit abscission (Walter et al. 1980; Siebert et al. 2006).

Approximately 35 days after planting, the square will be visible form. This is known as the first position square on the fruiting branch (Main 2012). The square goes through several stages of development prior to bloom including: pinhead square, match-head square, and candle shape square (Main 2012). Cotton will bloom for approximately six weeks (Ritchie et al., 2008, Main 2012,). A pollinated flower develops into a cotton boll (Ritchie et al., 2008). The flowering process takes several weeks, while an individual flower is pollinated in less than one day. Once the white flower opens, it is pollinated within several hours and later turns to a pink color and dries to expose the developing boll (Ritchie et al., 2008). When the cotton plant first blooms, it is typical for a given plant to have nine to ten nodes above white flower (NAWF). When a white flower appears typically on the fifth main-stem node downward the apical meristem, the cotton plant is developing the last harvestable boll (Bourland et al. 1992). Therefore, five NAWF is definitive for identifying cutout in cotton (Gerik et al. 1998). The shedding of squares, and sometimes flowers or young bolls is common and can be the result of water stress, prolonged cloudy weather, nutrient deficiencies, high temperatures, high populations, and insect damage (Wadleigh 1944; Jackson and Gerik 1990; Guinn 1982; Siebert et al. 2006; Main 2012). The process of boll development begins directly after pollination and continues until the last boll is opened (Main 2012).

The boll development process is represented by three phases: enlargement, filling, and maturation (Ritchie et al., 2008). During the enlargement phase, fibers elongate to maximum potential (Ritchie et al., 2008). During the filling phase, which usually occurs four weeks after flowering, fiber elongation ceases and cellulose is deposited into the elongated fiber and fills the voided space (Main 2012). Finally, the boll reaches its full mass, and seed maturation and boll dehiscence occurs (Main 2012). Harvest is usually in process approximately 140 days after planting (Ritchie et al., 2008). Harvest aids are used to remove vegetative growth, control regrowth, and enhance boll opening prior to harvest (Logan and Gwathmey 2002; Ritchie et al., 2008). Harvest aids give the producer more control over harvest timing and under optimal conditions, cotton can be harvested seven to ten days after defoliation (Ritchie et el., 2008).

Thrips

Thrips belong to the order Thysanoptera which consists of roughly 5,000 different species; however, few are pests in row crops (Layton and Reed 2002). Yield losses from thrips in Mississippi range from 10 to 304 kg ha^{-1} (Layton and Reed 2002). In 2014, yield losses of approximately 150,479 bales due to thrips damage were reported in the U.S. (Williams 2015). The order Thysanoptera is divided into two suborders - Tubulifera and Terebrantia. The genus Tubulifera lay their eggs on the surface of plant tissue whereas Terebrantia insert their eggs within plant tissue (Reed et al., 2006). Thrips species that feed on cotton belong to the suborder Terebrantia (Reed et al., 2006). Primary thrips species that are pests of cotton are part of the genus *Frankliniella* and consist of: western flower thrips [*F. occidentalis* (Pergande)], eastern flower thrips [*F.trittici* (Fitch)], and tobacco thrips [*F.fusca* (Hinds)] (Reed and Jackson 2002). Identifying these species in the field can be difficult. However, under adequate magnification physical differences can be seen (Reed and Jackson 2002). Dark-colored thrips on seedling cotton are usually labeled as tobacco thrips. Western flower thrips can range in color from light amber color to dark brown (Reed and Jackson 2002). More than 90% of adult thrips in Mississippi found on seedling cotton have been identified as tobacco thrips (Reed and Jackson 2002). In addition, the majority of thrips collected in the Mid-south are female (Reed et al., 2006).

Thrips are the smallest of all cotton insect pests, at less than 0.2 centimeters in size (Layton and Reed 2002). Thrips immigrating from host plants during early spring may infest cotton plants at emergence (Reed and Jackson 2002). Thrips uniformly infest an entire cotton field, unlike spotty or localized infestations that occur with other pests (Reed and Jackson 2002). Cotton is more susceptible to thrips injury than other row crops due to the slow development of the terminal bud in seedling cotton (Layton and Reed 2002). Thrips have piercing sucking mouth parts that allow them to pierce a leaf cell while inserting their maxillary stylets to consume the cellular fluids (Layton and Reed 2002). Air partially fills the damaged cell and gives the feeding sites a silvery sheen which eventually turns brown in color (Layton and Reed 2002). First symptoms of feeding will occur in small areas of the cotyledonary leaves and will eventually appear silver or whitish in color (Reed et al., 2001). Thrips damage on developing parts of the plant such as the terminal bud and undeveloped leaves is magnified as those leaves develop and expand (Layton and Reed 2002). Immature and adult thrips prefer smaller leaves and the terminal bud. Thrips damage typically results in ragged and crinkled leaves and as they mature becoming "possum-eared" (Herbert Jr. 2013; Reed et al., 2001). Uncontrolled thrips feeding can result in reduction in size of the first few true leaves (Reed et al., 2001). Plants subjected to heavy thrips pressure display a crinkled, tattered appearance that often curls upwards at the leaf margins (Layton and Reed 2002). Thrips damage is exacerbated under conditions such as cool weather or drought. During these conditions, plant development time is increased and cotton remains in susceptible growth stage longer (Layton and Reed 2002). Cotton fields that have heavy populations of thrips may have stunted growth; death of the terminal bud (resulting in "crazy cotton"), delayed fruiting, and reductions in plant stand (Layton and Reed 2002). Cotton yield may also be affected from weaker plants shedding younger buds and producing small bolls (Chaudhry and Guitchounts 2003).

A good scouting program is the first line of defense against insect pests in cotton (Greene et al., 2012). Scouting for thrips from emergence through the three to four leaf stage is critical as this is the time when cotton plants are most susceptible to injury (Catchot et al., 2013). When scouting for thrips, sample five to ten plants from several locations in the field (Layton and Reed 2002). With these samples, use a box with a white bottom with a1.27 cm hardware cloth over the top to improve collection of thrips. Beat the plants against the hardware cloth several times to dislodge the thrips and examine the number of thrips (Layton and Reed 2002). Examine 50 to 100 plants per field before determining an average number of thrips per plant (Layton and Reed 2002). The current threshold for thrips in cotton is one thrips per plant with immatures present (Catchot et al., 2013). Recommended thrips control practices on cotton in Mississippi include the use of seed treatments, in-furrow insecticides at planting, and application of foliar treatments (Reed et al., 2001). At-planting treatments are more effective in preventing yield loss than foliar sprays (Layton and Reed 2002). Excessive application rates of some at-planting treatments have been known to cause seedling injury. When cotton reaches the four-leaf stage and is growing vigorously, plants are generally considered safe from yield reductions caused by thrips (Catchot et al., 2013; Layton and Reed 2002).

Seed Treatments

Cotton is naturally susceptible to a variety of insect pests and requires proper protection to maximize effectiveness of inputs (Chaudhry and Guitchounts 2003). Thrips control in cotton is usually achieved through at-planting insecticide treatments (Cook et al., 2011). Generally, residual activity of at-planting insecticides ranges from two to four weeks (Cook et al., 2011). Insecticides such as thiamethoxam and imidacloprid are options for thrips control (Greene et al., 2002). Thiamethoxam and imidacloprid belong to the neonicotinoid class of chemistry and have been widely adopted by growers across the Cotton Belt (Stewart et al., 2013). The mode of action of the neonicotinoid insecticides is modeled after the natural insecticide, nicotine (Fishel 2005). Neonicotinoids attack the nervous system and causes excitation of the nerves and eventually paralysis which leads to death of the insect (Fishel 2005). As a group, neonicotinoids are very effective on sucking insects such as: thrips, aphids [Hemiptera: Aphididae], whiteflies [Hemiptera: Aleyrodidae], leaf- and plant-hoppers [Hemiptera; Membracidae], some micro lepidoptera and a several coleopteran pests (Elbert et al., 2008; Fishel 2005).

Thiamethoxam

Thiamethoxam is a second generation neonicotinoid developed by Ciba Crop Protection. Thiamethoxam has been on the market since 1998 as Actara® and Centric® for foliar treatment and Cruiser® for seed treatment use and is used in 115 crops in at least 64 countries (Maienfisch et al., 2001). Thiamethoxam is a crystalline, odorless compound with a low molecular mass, relatively high water solubility (4.1g liter^{-1} at 25ºC), and a low partition coefficient (Maienfisch et al., 2001). These properties assist rapid, efficient uptake in plants and xylem transport (Maienfisch et al., 2001). Half-life of thiamethoxam ranges from 34 to 75 days under favorable conditions but can be variable under unfavorable conditions (Maienfisch et al., 2001). Thiamethoxam decomposes at a moderately slow rate under laboratory conditions while under field conditions higher microbial activity as well as light exposure can promote faster degradation (Maienfisch et al., 2001). Thiamethoxam provides excellent control of early-season sucking insect pests in cotton such as thrips, aphids, and leaf hoppers (Maienfisch et al., 2001. Use rates ranging from 105 to 350g AI 100kg $^{-1}$ seed usually provide 21-45 days control (Maienfisch et al., 2001).

Imidacloprid

Imidacloprid is a highly effective insecticide developed in the U.S. by Miles Inc. and by Bayer worldwide (Mullins 1993). Imidacloprid is registered for use in more than 140 crops and more than 120 countries (Elbert et al., 2008). Imidacloprid was the first product of the neonicotinoid class of insecticides commercially introduced in the United States (Fishel 2005). Imidacloprid is a systematic insecticide that enters the pest through consumption or direct contact (Fossen 2006). Imidacloprid moves rapidly through plant tissues after application and may be present in leaves, vascular fluids, and pollen (Fossen 2006). Imidacloprid has a photolysis half-life of 39 days at the soil surface; however, when soil incorporated, soil half-life extends from 27 - 229 days (Fossen 2006).

Imidacloprid has long residual activity and is particularly effective against sucking insects and soil insects (Fishel 2005). Residual control of thrips may last from 11 to 33 days. In addition, higher use rates correlate with longer residual (Lentz and Austin 1994). Imidacloprid is used widely across the U.S. Cotton Belt for thrips control and has been shown to keep cotton plants free from severe insect infestation, result in normal vigor, and result in higher lint yield (Dobbs et al., 2006, Hossain et al., 2012).

Preemergence Herbicides

Herbicides are defined as crop-protecting chemicals used to kill weedy plants or interrupt their growth (Lingenfelter 2007). Herbicides provide an economic, effective way to control weeds and prevent soil erosion by reducing tillage. Herbicides are classified in several ways, including by weed control spectrum, chemical family, labeled crop usage, mode of action, and application timing or method. Herbicides are commonly grouped by placing them into families based on common chemistry. Herbicides are also grouped by mode of action based on the sequence of events from absorption of the herbicide into the plant until plant death and describe how the herbicide works to injure or kill the plant. Method of application such as broadcast, band, direct, and spot treatment applications are also used to group herbicides. Broadcast applications occur when a herbicide is sprayed in a blanket application over an entire field. Band applications are applied to a narrow strip over the crop row. A directed application is applied between the rows of the crop with little to no contact with the crop foliage. Spot treatments are only applied to areas where weed infestations occur within a field. Herbicide application timings include pre-plant incorporated (PPI), pre-plant, preemergence (PRE), postemergence (POST), or postemergence-directed (PD). Pre-plant incorporated applications occur when the herbicide is mechanically incorporated into the top two to three inches of the soil before the crop is planted. Pre-plant applications are applied to the soil before the crop is planted. Preemergence applications are made after the crop is planted but before it emerges while POST and PD applications are made after the crop emerges (Lingenfelter 2007).

Pre-plant or PRE applications are important in ensuring cotton has a competitive advantage over weeds (Ferrell et al., 2012). Because cotton is a slow emerging plant, it usually requires up to eight weeks of early season weed control to out-compete weeds for sunlight and achieve maximum yields (Buchanan and Burns, 1970; Buchanan 1992). Postemergence and PD applications can be used to extend weed control throughout the season (Ferrell et al., 2012). Insects, diseases, weather, and nutrient deficiencies are often causes of symptoms attributed to herbicide injury (Lingenfelter 2007). Presence of weeds in cotton disrupts cotton growth and can reduce yields.

Fluometuron

Fluometuron (Cotoran®, etc.) is a phenylurea herbicide. It is used in cotton as a PPI treatment at 1.8 kg ai ha^{-1} and PRE or POST at 1.1 - 2.2 kg ai ha^{-1} (Senseman 2007). Fluometuron controls many broadleaf and grass species including barnyardgrass [*Echinochloa crus-gali* L.], large crabgrass [*Digitaria sanguinalis* L.], fall panicum [*Panicum dichotomiflorum* Michx.], goosegrass [*Eleusine indica* L.], broadleaf signalgrass [*Urochloa platyphylla* Nash], common cocklebur [*Xanthium strumarium* L.], morningglory [*Ipomoea* spp.] common ragweed [*Ambrosia artemisiifolia* L.], sicklepod [*Senna obtusifolia* L.], and others. Fluometuron can be applied in water or liquid fertilizer. Fluometuron is a photosystem II (PSII) inhibitor and is readily absorbed by the roots after application and is translocated predominately through the xylem. Symptoms of fluometuron injury in susceptible plants begin as interveinal chlorosis of the leaves, followed by increasing chlorosis and necrosis. Cotyledons may show chlorotic areas and older leaves will often show more damage than new growth. Fluometuron has an average soil half-life of 85 days.

Fluometuron can be applied pre-plant, PRE, or POST. The use of fluometuron as a pre-plant or PRE combined with a soil-applied organophosphate insecticide at planting may cause injury to cotton. A combination of fluometuron with clomazone may also result in crop injury. Rainfall that is sufficient to germinate seeds is adequate to activate fluometuron. If dry conditions occur after application, herbicidal activity will be delayed or reduced. Fluometuron provides up to two and a half weeks of residual weed control. Broadcast rates of fluometuron vary depending on the soil texture of the field. A one-time maximum application rate on sandy loams a rate of 1.1 kg ai ha^{-1} is recommended whereas on silt and clay loams a rate of 1.8 kg ai ha^{-1} is recommended and for clays 2.2 kg ai ha^{-1} is recommended. A minimum of at least 20 days must pass between the first and second application of fluometuron (Anonymous 2014b).

Diuron

Diuron (Direx®, etc.) is a phenylurea herbicide. Diuron may be used PRE at 0.6 - 2.2 kg ai ha^{-1}. Diuron controls many annual weeds at lower rates and at higher rates controls selected perennial weeds (Senseman 2007). Diuron is a PSII inhibitor and is readily absorbed by roots. Diuron is translocated rapidly into the roots mainly through the xylem. Symptoms of diuron injury consists of foliar chlorosis around the veins (sometimes interveinal) followed by necrosis. The average soil half-life for diuron is 90 days.

Diuron must be applied after planting but before the cotton emerges. Only use diuron where cotton is planted on flat or raised seed beds. If moisture is not adequate to activate diuron or if soil becomes crusted before the crop emerges, shallow rotary hoeing is recommended before weeds become established. Broadcast application rates for diuron vary depending on soil texture. Diuron may be applied to sandy and silt loams at 0.9 kg ai ha^{-1}, in sandy and silt clay loams a rate of 1.1 kg ai ha^{-1}, and in silty clay or clay a rate of 1.8 kg ai ha^{-1}. If replanting is necessary, avoid disturbing the original seed bed to avoid possible crop injury (Anonymous 2014d).

S-metolachlor

S-metolachlor (Dual Magnum™, etc.) is a chloroacetamide herbicide that is used in cotton as a PPI, PRE, or POST treatment (Senseman 2007; Anonymous 2014c). *S*-metolachlor controls yellow nutsedge [*Cyperus esculentus* L.] as well as many annual grass weeds such as foxtail [*Setaria* spp.], barnyardgrass [*Echinochloa crus-galli* L.], crabgrass [*Digitaria* spp.], fall panicum [*Panicum dichotomiflorum* Michx.], broadleaf signalgrass [*Urochloa platyphylla* Nash], witchgrass [*Panicum capillare* L.], and red rice [*Oryza sativa* L.] (Senseman 2007). It also controls certain broadleaf weeds such as redroot pigweed [*Amaranthus retroflexus* L.], carpetweed [*Mollugo verticillata* L.], and Florida pusley [*Richardia scabra* L.]. *S*-metolachlor inhibits the biosynthesis of several plant components such as fatty acids, lipids, proteins, isoprenoids, and flavonoids. *S*-metolachlor is absorbed by emerging shoots, particularly grass coleoptiles with some root absorption. Symptoms of *S*-metolachlor injury on susceptible species usually manifest themselves by failed emergence. Grass injury appears as malformed and twisted seedlings that have tightly rolled leaves that may not unroll properly. Broadleaf weeds typically have cupped or crinkled leaves that have a heart shaped appearance. *S*-metolachlor doesn't persist long enough to affect crops in the next growing season, and has a soil half-life of three to five months.

S-metolachlor applied PRE should be applied to the soil surface at planting or after planting but before weed or crop emergence (Anonymous 2014c). At least 1.27 cm rain or irrigation must occur within 10 days after application to activate *S*-metolachlor. If insufficient rainfall is received, cultivation may be used to incorporate and activate *S*-metolachlor. Application rates of *S*-metolachlor vary depending on soil texture. Broadcast application rates range from 0.5 -1.1 kg ai ha^{-1} on sandy loams, on silt loam application rates range from 0.7- 1.4 kg ai ha^{-1} is recommended, and on clay soils application rates range from 1.1-1.4 kg ai ha^{-1}.

Fomesafen

Fomesafen (Reflex®, etc.) is a diphenylether herbicide (Senseman 2007). Fomesafen can be used PPI and PD in cotton (Anonymous 2014a). Fomesafen controls many annual broadleaf weeds including morningglorry [*Ipomoea* spp.], pigweed [*Amaranthus* spp.], jimsonweed [*Datura stramonium* L.], wild mustard [*Sinapis arvensis* L.], black nightshade [*Solanum nigrum* L.], and ragweed [*Ambrosia* spp.] (Senseman 2007). Fomesafen is a protoporphyrinogen oxidase inhibitor that inhibits the oxidation of protoporphyrinogen IX to protoporphyrin IX. Lipids and proteins are attacked and oxidized, resulting in the loss of chlorophyll and carotenoids as well as leaky membranes which allows cells and cell organelles to dry and disintegrate. Within one to three days, susceptible plants will have leaves becoming chlorotic, desiccated, and necrotic. Sublethel rates may produce foliar "bronzing" on younger leaves and droplet drift will cause bleached spots and flecks on leaves. The average half-life of fomesafen in soil is 100 days.

Fomesafen may be used pre-plant on cotton planted at least 1.9 cm in depth. Cotton injury will appear as crinkling or spotting of cotton foliage and stunted growth. Fomesafen may be applied PRE on a sandy loam, loamy sand, or a sandy clay loam soil. Fomesafen may be applied at 1.2 -1.8 L ha^{-1}. Fomesafen applied PRE is not recommended on silt loam and clay textured soils as crop injury will likely occur (Anonymous 2014a).

Soil Texture

Soil texture is a term used to categorize different sizes of mineral particles in a soil. Soil textures from largest to smallest include very coarse sand, coarse sand, medium sand, fine sand, very fine sand, silt, and clay having the smallest particles. Table 1.1 further illustrates the size limits for each soil in the USDA soil textural classification system (Brown 2003).

Table 1.1 Name of soil separate with corresponding diameter limits.

Soil Separate	Diameter limits (mm)
Very coarse sand	2.00- 1.00
Coarse sand	1.00- 0.50
Medium sand	0.50- 0.25
Fine sand	0.25- 0.10
Very fine sand	0.10- 0.05
Silt	0.05- 0.002
Clay	less than 0.002

There are twelve major soil textural classes defined by the United States Department of Agriculture. Classes are determined through mechanical analysis of soil samples with the total percentage of sand, silt, and clay content in the sample determining the textural name of the soil (Brown 2003). Figure 1.1 is a layout of the textural triangle used to determine texture (USDA/NRCS 2013).

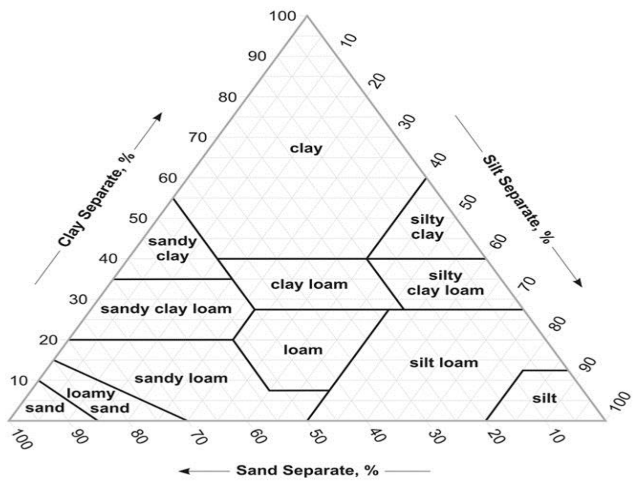

Figure 1.1 Soil Texture Triangle

Soil texture characteristics are a good tool to help determine land use and management (Brown 2003). Physical, chemical, and microbial factors of soil affect herbicide persistence and residues within the soil. Residual herbicides are applied to soil for weed control during a growing season. Soil composition affects herbicide persistence through absorption, leaching, and volatilization (Hager and Nordby, 2007). Climatic variables such as moisture, temperature, and sunlight affect herbicide degradation rates within the soil (Hager and Nordby, 2007).

Crop response to herbicides is affected by various factors such as variety, soil type, and environmental conditions after planting, which makes predicting crop injury difficult. Herbicides that persist in the soil from previous years can enhance crop injury. Depending on the soil type and texture, herbicide half-life can be extensive and carryover to the next crop may result in crop injury (Gannon et al. 2014). To determine if carryover injury may occur, a bioassay can be performed to determine whether a herbicide is present in large enough quantities to injure the subsequent crop (Hager and Nordby 2007). Herbicide movement through the soil also determines whether crop injury will occur. Herbicide residue concentrated in the top 7.6 cm rather than distributed throughout the 15.2 cm seed bed, poses a greater risk of crop injury is likely. Soils with high sand content can result in greater subsequent crop injury. Crop injury is also more likely with more coarse soils under cool, wet weather conditions (Hager and Nordby 2007).

Project Justification

Many factors contribute to severity of thrips damage to seedling cotton in Mississippi. Factors such as temperature, varietal maturity, and choice of prophylactic at-plant thrips control options influence potential damage caused by thrips. Nearly all cotton seed in Mississippi is treated with imidacloprid or thiamethoxam insecticide. Often, these products are applied with fungicidal and nematode products in various combinations. Since their introduction in the early 1990's, insecticide seed treatments quickly replaced in-furrow granules such as aldicarb (Temik) due their low mammalian toxicity and ease of application. However, since 2011, producers have observed an increase in damage from thrips compared to previous years and more foliar insecticide applications have been needed (Williams 2015). In addition, as glyphosate-resistant Palmer amaranth

[*Amaranthus palmeri* S.Wats.] has spread throughout Mississippi, the use of PRE herbicides has also become more prevalent. Preemergence herbicides often slow early season growth of seedling cotton plants. Therefore, it is hypothesized that the increased use of PRE herbicides is correlated with increased damage from thrips observed in Mississippi. In addition, research is needed to quantify if differences in type of seed treatment has an influence on efficacy against tobacco thrips and if agronomic factors such as planting date can be manipulated to maximize efficacy of PRE herbicides while minimizing thrips infestation in cotton.

References

Anonymous. 2013. Cotton Belt. Columbia Electronic Encyclopedia, 6th Edition [serial online]. September 2013. Available from: Literary Reference Center, Ipswich, MA. Accessed 22 April 2014.

Anonymous. 2014a. Reflex herbicide label. Available at http://www.cdms.net. (Verified 09 Sept. 2014).

Anonymous. 2014b. Cotoran herbicide label. Available at http://www.cdms.net. (Verified 09 Sept. 2014).

Anonymous. 2014c. Dual Magnum herbicide label. Available at http://www.cdms.net. (Verified 09 Sept. 2014).

Anonymous. 2014d. Direx herbicide label. Available at http://www.cdms.net. (Verified 09 Sept. 2014).

Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main- stem node counts. *J. Prod. Agric.*5: 532- 538.

Brown, R.B. 2003. Soil Texture. *University of Florida IFAS Extension*. Publication: SL29

Buchanan, G.A. 1992. Trends in Weed Control Methods. In McWhorter, G.M., J.R. Abernathy (ed). Weeds of Cotton: Characterization and Control. p. 47-72.

Buchanan, G.A., and Burns E.R. 1970. Influence of weed competition on cotton. *Weed Sci.* (18): 149-154.

Catchot, A., B. Adams, C. Allen, J. Bibb, D. Cook, D. Dodds, J. Gore, R. Jackson, B. Von Kanel, E. Larson, B. Layton, R. Luttrell, and F. Musser. 2013. Pest Management Guide for Agronomic Crops 2013. *Mississippi State University Extension Service*. Publication 2471.

Chaudlhry, M. Rafiq and Andrei Guitchounts. 2003. Cotton Facts. Common Fund for Commodities Technical paper No. 25: pp. 35-83

Cook, D., A. Herbert, D.S. Akin,and J. Reed. 2011. Biology, Crop Injury, and Management of Thrips (Thysanoptera: Thripidae) Infesting Cotton Seedlings in the United States. *J. Int. Pest Mgmt.* B1-B9

Dobbs, R.R., N.W. Buehring, J.T. Reed and M.P. Harrison. 2006. Thrips control response to Temik and Gaucho in UNR cotton. *Mississippi Agril. Forest Exp. Station, Mississippi State Univ.* USA. 23: 1-3.

Elbert, A., M. Haas, B. Springer, W. Thiclart,and R. Nauen. 2008. Applied Aspects of Neonicotinoid Uses in Crop Protection. *Pest Mgmt. Sci.* (64): 1099-1105

Ferrell, J.A., G.E. MacDonald, R.Leon. 2012. Weed Management in Cotton. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication SS-AGR-04.

Fishel, F. M. 2005. Pesticide Toxicity Profile: Neonicotinoids Pesticide. *Florida Cooperative Extension Service*. Publication PI-80

Fossen, M. 2006. Environmental Fate of Imidacloprid. *Environmental Monitoring Department of Pesticide Regulation*.

Gannon, T.W., A.C, Hixson, K.E. Keller, J.B. Weber, S.Z. Knezevic, and F.H. Yelverton. 2014. Soil Properties Influence Saflufenacil Phytotoxicity. *Weed Tech.* 62(4): 657-663.

Gerik, T.J., D.M. Oosterhuis, and H.A. Torbert. 1998. Managing Cotton Nitrogen Supply. *Advances in Agronomy* 64: 115- 147.

Greene, J. K., C. Capps, B. Myers, J. Reed. 2002. Control Options for Thrips in Southeast Arkansas. *Summaries of Arkansas Cotton Research*. pp. 254-258

Greene, J.K. 2013.2013 South Carolina Pest Management Handbook for Field Crops. *Clemson Cooperative Extension*. Publication APT 1. 93-107

Guinn, G. 1982. Causes of Square and Boll Shedding in Cotton. U.S. Department of Agriculture Technical Bulletin No. 1672.

Hager, A. G., and D. Nordby. 2007. Herbicide Persistence and How to Test for Residues in Soils. *Illinois Agricultural Pest Management Handbook.*

Herbert Jr., D.A. 2013. Pest Management Guide Field Crops 2013. *Virginia Cooperative Extension*. Publication 456-016.

Hossain, S. A., Baque, M. A., M.R. Amin,and Chun, I. J. 2012. Field evaluation of imidacloprid as an insecticidal seed treatment of cotton cultivar with particular references to sucking pest, predator and yield. *Our Nature* Volume 10(1) pp. 44-52. Web Accessed 9 September 2013. http://ipm.illinois.edu/pubs/iapmh/15chapter.pdf.

Jackson, B.S., and T.J. Gerik. 1990. Boll shedding and boll load in nitrogen-stressed cotton. *Agron. J.* 82: 483-488.

Layton, B. and J.T. Reed. 2002. Biology & Control of Thrips on Seedling Cotton. *Mississippi State University Extension Service*. Publication 2302.

Lentz, G.L. and N.B. Austin. 1994. Control or early season thrips on cotton with Gaucho (NTN33893) seed treatments. p. 847-849. *In* Proc. Beltwide Cotton Conf., San Diego, CA 5-8 Jan.1994. Natl. Cotton Counc. Am., Memphis, TN.

Lingenfelter, D.D., N.L. Hartwig. 2007. Introduction to Weeds and Herbicides. *Pennsylvania State University*. Publication UC175

Logan, J. and C.O. Gwathmey. 2002. Effects of weather on cotton responses to harvest-aid chemicals. *J. Cot. Sci.* 6:1-12.

Maienfisch, P., M. Angst, F. Brandl, W. Fischer, D. Hofer, H. Kayser, W. Kobel, A. Rindlisbacher, R. Senn, A. Steinimann, and H. Widmer. 2001. Chemistry and Biology of thiamethoxam: a second generation neonicotinoid. *Pest Mgmt. Sci.* (57): 906- 913

Main, C. L. 2012. Cotton Growth and Development. *University of Tennessee Extension*. Publication: W287

Mullins, J.W. 1993. Imidacloprid: A new nitroguanidine insecticide. *ACS Synposium series American Chemical Society*. pp. 183-198.

Reddy, V.R., D.N. Baker, and H.F. Hodges. 1990. Temperature and mepiquat chloride effects on cotton canopy architecture. *Agron. J.* 82:190-195

Reddy, V.R., D.N. Baker, and H.F. Hodges. 1991. Temperature effect on cotton canopy growth photosynthesis and respiration. *Agron. J.* 83:669-704.

Reed, J. T., C. Allen, R. Bagwell, D. Cook, E. Burris, B. Freeman, R. Leonard, G. Lentz. 2006. A Key to the Thrips on Seedling Cotton in the Mid-southern United States. Bulletin 1156, *Office of Agriculture Communication, Division of Agriculture, Forestry, and Veterinary Medicine at Mississippi State University, Mississippi State,* MS.

Reed, J. T. and C.S. Jackson. 2002. Thrips on Mississippi Seedling Cotton. *Mississippi State University Extension Service*. Bulletin 1124.

Reed, J. T., E. Burris, C. Allen, R. Bagwell, D. Cook, B. Freeman, G. Herzog, G. Lentz, R. Leonard. 2001. Thrips (Thysanoptera: Thripidae) A Multi-State Survey: Mississippi. *Mississippi State University Extension Service*. Vol.22 No.15.

Ritchie, G. 2008. University of Georgia College of Agricultural and Environmental Sciences. *University Copperative Extension Service.* Web Accessed. 20 August 2013.

Senseman, S.A. 2007. Herbicide Handbook. *Weed Science Society of America*.

Siebert, J.D., A.M. Stewart, and B.R. Leonard. 2006. Comparative Growth and Yield of Cotton Planted at Various Densities and Configurations. *Agron. J.* 98:562-568.

Stewart, S., S.D. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R. Jackson, D. Kerns, B.R. Leonard, G. Lorenz, S. Micinski, D. Reisig, P. Roberts, G. Stude Baker, K. Tindall, M. Toews. 2013. Survey of Thrips Species Infesting Cotton across the Southern U.S. Cotton Belt. *J. Cot. Sci.*17(2): 1-7

USDA/NASS. 2014. Cotton Production Data. Agricultural Statistics Board, NASS, and USDA: Accessed: 22 April 2014. http://www.usda.gov/nass.

USDA/NRCS. 2013. Soil Textural Triangle. Web Accessed 9 September 2013. http://soils.usda.gov.

Wadleigh, C.W. 1944. Growth Status of the Cotton Plant as Influenced by the Supply of Nitrogen. Arkansas Agric. Exp. Sta. Bulletion 446.

Walter, H., H.W. Gausman, F.R. Rittig, L.M. Namkin, D.E. Escobar, and R.R. Rodriquez. 1980. Effects of mepiquat chloride on cotton plant leaf and canopy structure and dry weights of its components. p. 32-35.*In* Proc. Beltwide Cotton Prod. Res. Conf., St. Louis, MO. 6-10. Jan. Natll. Cotton Counc. Am., Memphis, TN.

Williams, M.R. 2015. Cotton Insect Losses 2014. *In Press* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 2015. Natl. Cotton Counc. Am., Memphis, TN.

CHAPTER II

EVALUATION OF PLANTING DATE, VARIETY, AND PRE HERBICIDE ON THRIPS INFESTATION AND COTTON GROWTH, DEVELOPMENT, AND YIELD

Abstract

Planting cotton as soon as environmental conditions are favorable is crucial for successful production; however, inclement weather conditions are often present early in the season and can reduce plant populations as well as seedling vigor. Early season thrips infestations and preemergence (PRE) herbicides can also impact early season growth and development of cotton. Research was conducted in 2013 and 2014 at the Black Belt Branch Experiment Station near Brooksville, MS, the R.R. Foil Plant Science Research Center near Starkville, MS, and at the Delta Research and Extension Center in Stoneville, MS to evaluate the impact of planting date, varietal maturity, and PRE herbicide on thrips infestations in cotton. Varieties used in this study included DP 0912 B2RF (short season) and DP 1252 B2RF (long season). Planting dates included mid- April, mid- May, late-May, and mid- June. Due to inclement weather in 2013, the mid- April planting date was not utilized at any location. Acceleron® N seed treatment (thiamethoxam + pyraclostrobin +abamectin) was utilized on each variety at each location and fluometuron + *S*-metolachlor was applied PRE at 1.12 + 1.07 kg ai ha^{-1}. In addition, an untreated check (with respect to herbicides) was included for comparison purposes. Cotton biomass at the

2-leaf stage was greatest when DP 0912 B2RF was planted in late-May at 3.2 g per five plants. Based on PRE herbicides, cotton treated with fluometuron + *S*- metolachlor had less biomass at the two- leaf stage. Immature thrips counts were greatest on late May planted cotton at both the two- and four- leaf stages. Thrips injury symptomology was more apparent on cotton planted in mid and late May. Cotton height at the four- leaf stage was greatest when DP 0912 B2RF was planted in mid- June, or in the absence of a PRE herbicide application. Delayed maturity, as defined by nodes above cracked boll, was observed for both varieties when planting after mid- May. Lint yields were affected by PRE herbicide. Cotton treated with a PRE herbicide resulted in a significant yield loss. Lint yields affected by planting date were greatest when DP 0912 B2RF was planted in mid-April, mid- May, and late May or with DP 1252 B2RF planted in mid-April and mid- May. Lint yields from these combinations ranged from 2195 kg ha^{-1} to 2429 kg ha^{-1}.

Introduction

Delayed early season cotton (*Gossypium hirsutum* L.) growth increases vulnerability to tobacco thrips (*Frankliniella fusca* [Hinds]) infestations. In 2012, tobacco thrips caused yield losses of 5,057 bales in MS (Stewart et al. 2013; Williams 2013). Yield losses ranging from 10 to 304 kg lint ha^{-1} have been observed due to thrips infestation (Layton and Reed 2002). Early season thrips infestations cost cotton growers \$41.77 ha^{-1} in 2012 (Williams 2013). Generally, high input costs are associated with cotton production. Seed treatments containing insecticides have become commonplace in cotton production for thrips management to minimize yield loss (Layton and Reed 2002; Cook et al. 2011; Stewart et al. 2013).

Planting cotton as early as environmental conditions will allow is crucial for successful production. Many producers prefer to plant as early as possible to facilitate earlier harvest. Early planting in cotton in Mississippi occurs in mid- April when soil temperatures have reached at least 15.5^{o}C. Early planting has shown to significantly increase lint yields in cotton production systems (Bibro and Ray 1973; Pettigrew 2002; Chaudhry and Guitchounts 2003; Davidonis et al. 2004; Adams et al. 2013). Tobacco thrips populations peak during the early portion of the growing season (Morsello et al. 2008). Planting cotton at earlier calendar dates has been shown to reduce later season insect pests (Pettigrew 2002; Adams et al. 2013). Variety selection decisions are also important with respect to insect management plans, harvest planning, and yield goals (Dodds et al. 2011). Differences in cotton cultivar maturity range from10 to 14 days when comparing short-season to long-season varieties (Dodds et al. 2011). Cotton variety characteristics such as flowering period are important when trying to avoid mid-season and late-season insect pests (Luttrell 1994). Later maturing varieties are typically more exposed to late season insect pests that can reduce yield significantly compared to early maturing varieties that may avoid the pests (Adams et al. 2013).

Delaying cotton planting date typically decreases lint yield due to reduced length of the growing season (Kittock et al. 1987). Early planting dates in the Mississippi Delta have shown to increase yield by up to 10 % (Pettigrew 2002). However, planting cotton in cold and wet conditions that are often present early in the season can reduce plant populations as well as seedling vigor (Wrather et al. 2008). Cotton is naturally slow to develop in early growth stages and reduced early season growth due to environmental conditions can exacerbate the need for thrips management (Cook et al. 2011; 2013).

Cotton is susceptible to thrips damage from emergence until the four leaf stage (Catchot et al. 2013).

Along with weather conditions at planting, insect and weed management are critical for vigorous early season growth. Due to the presence of glyphosate-resistant (GR) weeds across the Cotton Belt, predominantly Palmer amaranth [*Amaranthus palmeri* (S. Wats.)], cotton producers have resumed applying preemergence (PRE) residual herbicides at planting to ensure a competitive advantage over early season weeds (Culpepper 2009; Irby et al., 2010; Ferrell et al. 2012). Use of PRE herbicides typically results in significant yield increases compared to systems where PRE herbicides are not used when GR weeds are present (Everman et al. 2009). However, application of PRE herbicides can result in cotton injury and slow development of seedling cotton which can exacerbate injury symptoms from insects, disease, weather, and nutrient deficiencies (Kendig et al. 2007; Ikram et al. 2012; Lingenfelter 2007). Main et al. (2012) found that PRE herbicide injury can decrease cotton lint yields up to 25%.

Many factors contribute to severity of thrips injury to seedling cotton in Mississippi. Factors such as temperature, varietal maturity, PRE herbicide, and choice of prophylactic at-plant thrips management options all influence potential damage caused by thrips. Producers often weigh the risk-reward of planting cotton early and the impact on yield of this practice. However previous research evaluating the effect of planting date and PRE herbicide application on cotton growth, development, and yield as well as thrips infestation is lacking. Therefore, this research was conducted to determine the effect of planting date, PRE herbicide application, and varietal maturity on thrips infestation as well as cotton growth, development, and yield.

Materials and Methods

Studies were conducted at the R.R Foil Plant Science Research Center in Starkville, MS and at the Delta Research and Extension Center in Stoneville, MS in 2013 and 2014. In 2013, this study was also conducted at the Black Belt Branch Experiment Station near Brooksville, MS. Treatments were arranged in a factorial arrangement within a randomized complete block design with four replications. Factor A consisted of four planting dates that encompassed the normal planting window for MS (Table 2.1). Soil texture at each location, cotton planting dates, PRE herbicide application dates, application equipment, and harvest dates varied across locations (Table 2.1). Factor B consisted of varietal maturity and included DP 0912 B2RF (short-season) and DP 1252 B2RF (long season) (Monsanto Company, St. Louis, MO). Factor C consisted of PRE herbicide and included *S*-metolachlor (Dual Magnum- Syngenta Crop Protection, Greensboro, NC) at 1.07 kg ai ha^{-1} and fluometuron (Cotoran 4L- Makhteshim Agan of North America, Raleigh, NC) at 1.12 kg ai ha^{-1}. An untreated check with respect to herbicides was included at each planting date. Rainfall events occurred within 24 hours after PRE herbicide application in both years at all locations. Soils were classified as follows at the experimental locations: Brooksville- Brooksville silty clay; Starkville- Leeper silty clay loam; and Stoneville- Bosket very fine sandy loam.

Plots consisted of 4-97 cm rows that were 12.2 m in length in Starkville and Brooksville and 4-102 cm rows that were 12.2 m in length in Stoneville. Cotton seed of both varieties were treated with Acceleron N (metalaxyl at 0.014 mg a.i. per seed + pyraclostrobin at 0.04 mg a.i. per seed + ipconazole at 0.002 mg a.i. per seed + fluxapyroxad at 0.018 mg a.i. per seed + thiamethoxam at 0.375 mg a.i. per seed+

abamectin at 0.15 mg a.i. per seed). Preemergence herbicides were applied at planting with recommended application volumes, pressure, and spray tips at all locations in each year (Table 2.1). Furrow irrigation was utilized at the Starkville and Stoneville locations as needed while Brooksville was grown under dry land conditions. All plots were maintained weed free throughout the growing season using POST, non- residual herbicides. In addition, with the exception of thrips, insecticides, plant growth regulators, fertilizers, and harvest aids were applied based on Mississippi State University Extension Service recommendations. Nitrogen was applied at 134 kg ha^{-1} as 32% UAN with a ground driven knife applicator, in split application at all locations in both years. The initial application was made following planting and the second application was made approximately 35 days after planting.

Data collection included the following: stand counts, injury ratings, biomass, and thrips populations at 14 days after planting (DAP); plant height at the four- leaf stage, pinhead square, and at first bloom; nodes above white flower (NAWF) at first bloom, nodes above cracked boll (NACB), prior to harvest aid applications and nodes above; and yield.

Cotton biomass at the two- and four- leaf stage was collected from five randomly selected plants from each plot which were cut at the soil surface, placed into paper bags, and dried in a forced air dryer for 72 hours at 70^{o}C. After drying, plants were weighed on an analytical balance to determine dry weight biomass. Thrips populations were sampled using the whole plant technique and washed using a technique modified from that of Burris et al. (1989; 1990). Five plants were selected randomly from each plot and clipped below the cotyledon leaves and quickly placed into self-sealing bags. The bags were brought to the laboratory and filled with a solution containing 10% bleach and soap. Cotton plants were allowed to soak in bleach and soap solution for 20 minutes. Plants were then washed over a standard No. 100 sieve. Thrips were then separated from the sieve using an alcohol solution in a 500 ml squirt bottle onto 9-cm white filter paper marked with gridlines for counting using a vacuum filtration system (Reisig et al. 2012). Filter paper was then placed into petri dishes from which thrips were separated based on color and counted using microscopy. Adult thrips that were dark in color were considered tobacco thrips while lighter colored adult thrips were considered other species. Stewart et al. (2013) observed 98% of thrips in MS were tobacco thrips. Immature thrips were marked "immature" due to inability to key to species. Plant heights were determined by measuring from the soil level to the apical meristem. Nodes above white flower (NAWF) were determined by counting the number of nodes on the main-stem from the uppermost first position white flower (Bourland et al. 1992). Nodes above cracked boll (NACB) were determined by counting the number of nodes between the uppermost first position cracked boll and the uppermost first position harvestable boll. The center two rows of each plot were harvested using a spindle-type cotton picker modified for small plot research. Lint yield for each plot was calculated from lint percent obtained from ginning each individual plot sample. Data were subjected to analysis of variance using the PROC MIXED procedure of SAS 9.3 (SAS institute; Cary, NC). Means were separated using Fisher's Protected LSD ($\alpha \leq 0.05$). Locations were treated as a random effect and data were pooled over experimental locations to allow for inferences of the treatments for a range of environments (Carmer et al. 1989). Degrees of freedom were calculated using the Kenward- Roger method.

Results and Discussion

Stand counts collected 14 days after planting (DAP) were affected by variety and planting date (Table 2.2). Stand counts collected 14 DAP were greater for DP 0912 B2RF at 109,421 plants ha^{-1} than for DP 1252 B2RF at 97,318 plants ha^{-1} (data not shown). These data are in agreement with Telenko and Donahoe (2014) who found greater plant populations of DP 0912 B2RF when seeded at equivalent rates compared to other early season cotton varieties. Stand counts 14 DAP based on planting dates ranged from 87,932 to 111,891 plants ha^{-1} (Table 2.3). Stand counts at 14 DAP indicated that cotton planted in mid- May, and after resulted in greater plant populations than those from the mid-April planting date (Table 2.3). Reductions in cotton stand counts at 14 DAP have been observed when flumioxazin was applied at planting at 0.06 and 0.09 kg ha^{-1} compared to nontreated control (Berger et al. 2012). In the current experiment, none of the PRE herbicides used reduced stand counts.

An interaction between planting date and variety was observed for cotton biomass collected at the two-leaf growth stage (Table 2.2). In addition, PRE herbicide application had a significant effect on cotton biomass collected at the two-leaf growth stage. There was no difference in biomass between the two varieties at the mid-April and mid- May planting dates. DP 0912 B2RF had significantly greater biomass than DP 1252 B2RF at the mid-May and early-June planting dates (Figure 2.1). At later planting dates, the early maturing variety DP 0912 B2RF was more vigorous than the later maturing variety DP 1252 B2RF at the two- leaf stage. Cotton to which no PRE was applied had significantly greater biomass at the two-leaf stage regardless of variety or planting date (Figure 2.2).

Previous research has shown that PRE herbicides can reduce cotton biomass (Askew et al. 2002).

Variety and PRE herbicide did not have an effect on immature thrips counts nor were any significant interactions observed. Planting date significantly impacted immature thrips counts at the two- and four- leaf growth stages (Table 2.2). Immature thrips counts ranged from 3 to 76 thrips per 5 plants at the two-leaf growth stage and ranged from 44 to 225 thrips per 5 plants at the four-leaf growth stage. Cotton planted in late May had significantly more immature thrips at both two- and four- leaf growth stages compared to all other planting dates (Table 2.3). In addition, the least number of immature thrips were collected from two- and four-leaf cotton planted in mid-April. Furthermore, similar numbers of immature thrips were observed on four-leaf cotton for mid-April and mid-June planting dates (Table 2.3). These findings are similar to Morsello et al. (2008) who observed thrips populations peaked in mid- May and declined before May 31. In addition, Reitz (2002) found immature thrips numbers peaked in early May. Thrips numbers and visual damage ratings peaked in May, which could be due to destruction of overwintering habitats and moving to host row crops such as cotton (Cook et al. 2011).

There were no interactions between variety, planting date, and PRE herbicide for plant height at the four- leaf stage (Table 2.2). However, the main effects of each were significant for plant height at the four- leaf stage. Height of DP 0912 B2RF at the four-leaf growth stage was significantly greater (21 cm) compared to DP 1252 B2RF (20 cm) (Figure 2.3A). Cotton height at the four-leaf growth stage ranged from 16 to 27 cm depending on planting date. Four- leaf cotton planted in mid- June was significantly taller than four- leaf cotton from any other planting date (Figure 2.3B). Four- leaf cotton planted in mid- May was significantly shorter than all other plantings. At the four- leaf growth stage, cotton planted in mid-April was significantly shorter than cotton planted in late May and mid- June but significantly taller than cotton planted in mid- May. These results are similar to those observed by Pettigrew and Meredith (2009) where cotton planted earlier in the growing season was stunted by cold weather and was shorter than cotton planted later in the season. Cotton that did not receive a PRE herbicide treatment was significantly taller than cotton plants treated with *S*-metolachlor + fluometuron (Figure 2.3C). Askew et al. (2002) reported PRE herbicide application resulted in up to 12% reductions in cotton plant height. Preemergence herbicide use may also stunt early season cotton growth by up to 15% (Main et al. 2012). Differences in maturity between varieties can also contribute to height differences (Wumbei, 2014). Wumbei (2014) found that later planted cotton was taller than earlier planted cotton.

Cotton height at pinhead square was affected by planting date and PRE herbicide; however, no interactions were observed (Table 2.2). Cotton height at pinhead square ranged from 31 to 37 cm, depending on planting date. Cotton planted in mid- June was significantly taller at pinhead square than cotton at pinhead square from all other planting dates at pinhead square (Table 2.3). Cotton not treated with a PRE herbicide was significantly taller than cotton treated with *S*-metolachlor +fluometuron for heights collected at pinhead square (data not shown).

An interaction was present for cotton height at first bloom between variety and planting date (Table 2.2). Cotton heights at first bloom ranged from 68 to 90 cm. DP 1252 B2RF was taller than DP 0912 B2RF at all planting dates (Figure 2.4). Cotton heights at first bloom were greater when DP 1252 B2RF was planted in mid- June when compared to both varieties at all other planting dates (Figure 2.4). DP 1252 B2RF was significantly taller when planted in mid-April compared to the mid- May planting date; however, DP 0912 B2RF planted in mid-April and mid- May produced similar heights at first bloom (Figure 2.4).

Planting date also affected NAWF at first bloom which ranged from 7.6 to 8.1 (Table 2.2). Cotton planted in mid- April and late- May had greater NAWF counts than other planting dates (Table 2.3). Under normal growing conditions, nine to ten NAWF at first bloom is common (Edmisten, 1993). Lower NAWF counts indicate stress from growing conditions while higher NAWF at first bloom could be due to excess nitrogen or poor fruit retention (Edmisten, 1993).

Nodes above cracked boll (NACB) is an indicator of plant maturity (Hake et al. 1996). Higher NACB counts represent a less mature plant whereas a lower NACB count indicates a more mature plant. There was a significant interaction between variety and planting date for NACB (Table 2.2). There were no significant differences in NACB among varieties planted in mid-April (Table 2.4). However, there were differences among varieties planted in mid- May and late-May for NACB. DP 1252 B2RF planted in mid- May and late May was less mature than DP 0912 B2RF at the end of the season. Differences in NACB are a result of DP 0912 B2RF being an early maturing variety while DP 1252 B2RF being a full season variety.

An interaction between variety and planting date was observed for lint yields (Table 2.2). DP 1252 B2RF and DP 0912 B2RF planted in mid-April and mid- May yielded significantly greater than the same variety planted in mid- June (Table 2.4). In addition, DP 1252 B2RF planted in mid- April and mid- May yielded significantly greater than the same variety planted in late May. These data agree with Davidonis et al. (2004), who reported that lint yields for cotton planted early were significantly greater than cotton planted at late planting dates. However, DP 1252 B2RF produced less lint yield when compared to DP 0912 B2RF when planted in late May and mid- June (Table 2.4). Differences between the two varieties were significant at the mid- June planting date where DP 0912 B2RF yielded higher than DP 1252 B2RF. Preemergence herbicide had a significant effect on lint yields (Table 2.2). Cotton that did not receive PRE herbicide treatment had greater lint yields than cotton treated with *S*-metolachlor + fluometuron, regardless of planting date or variety (Figure 2.5). Main et al. (2012) reported a 23 to 25% yield reduction when fomesafen was applied preemergence compared to the non-treated control.

Results indicate that variety choice, planting date, and PRE herbicides can impact growth parameters of cotton. Preemergence herbicide is recommended for all cotton production systems. Although yields were decreased by PRE herbicide application, the benefit of PRE herbicides in areas where glyphosate- resistant weeds are present cannot be overstated. The presence of troublesome, competitive weeds can disrupt early season cotton growth and decrease yield potential. Also, early planting in conjunction with the appropriate variety can positively affect yields. Based on yield data, both early and later maturing varieties planted in mid-April and mid- May will maximize yields. However, planting a later maturing variety in the later season can result in less yield potential. These data show that an early maturing variety planted at a later planting date will produce a more vigorous, early crop and higher yields compared to later maturing varieties at a later planting date.

Table 2.1 Environmental conditions, cotton planting and PRE herbicide application dates, application equipment, and harvest dates for 2013 - 2014.

Environment	Soil Texture	Mid-April Planting Date**	Mid- May Planting Date**	Late May Planting Date**	Mid- June Planting Date**	Application Equipment	Spray Tip Nozzles	Application Volume	Pressure	Harvest Date
								--L ha^{-1}--	--kPa--	
Brooksville	Brooksvile silty clay	N/A	20 May 2013 294 DD60s	04 June 2013 507 DD60s	17 June 2013 742 DD60s	CO_2- pressurized backpack sprayer	1100015 TTI	140	317	29 October 2013
Starkville	Leeper silty clay loam	N/A	15 May 2013 219 DD60s	31 May 2013 455 DD60s	14 June 2013 692 DD60s	Tractor-mounted compressed air sprayer	110015 AIXR	140	428	18 October 2013
		23 April 2014 76 DD60s	05 May 2014 152 DD60s	22 May 2014 333 DD60s	18 June 2014 777 DD60s					19 October 2014
Stoneville	Bosket very fine sandy loam	N/A	15 May 2013 257 DD60s	30 May 2013 478 DD60s	17 June 2013 764 DD60s	Tractor-mounted compressed air sprayer	8002 XR	140	255	30 October 2013
		17 April 2014 86 DD60s	08 May 2014 253 DD60s	23 May 2014 434 DD60s	12 June 2014 751 DD60s					03 November 2014

**Planting dates with corresponding accumulative degree days at planting from 01 January of the corresponding year.

Table 2.2 Analysis of variance p-values for thrips counts and cotton growth parameters as affected by variety, planting date, ad PRE herbicide.

Source	Degrees of freedom	Stand Counts 14 DAP[a]	Cotton Biomass at 2 Leaf	Immature Thrips at 2 Leaf	Immature Thrips at 4 Leaf	Plant Height at 4 Leaf	Plant Height at Pinhead Square	Plant Height at First Bloom	NAWF[b]	NACB[c]	Lint Yield
Variety	1	0.0011	<0.0001	0.2482	0.0722	0.0007	0.0538	<0.0001	0.7491	<0.0001	0.1845
Planting Date	3	0.0008	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0206	<0.0001	<0.0001
PRE herbicide	1	0.6115	0.0026	0.6322	0.1683	0.0461	<0.0001	0.9695	0.1201	0.2863	0.0493
Variety x Planting Date	3	0.9185	0.0118	0.3711	0.1945	0.4815	0.1630	0.0006	0.5199	0.0002	0.0065
Variety x PRE herbicide	1	0.4614	0.9582	0.9629	0.8583	0.2211	0.1949	0.4038	0.4369	0.6359	0.7911
Planting Date x PRE Herbicide	3	0.6378	0.1170	0.8812	0.9188	0.3696	0.2462	0.1646	0.2383	0.7925	0.3997
Variety x Planting Date x PRE herbicide	3	0.0866	0.9615	0.6626	0.9299	0.4640	0.8086	0.1831	0.5306	0.5842	0.5360

[a]Days after planting.
[b]Nodes above white flower.
[c]Nodes above cracked boll.

Table 2.3 Stand counts 14 days after planting, cotton height at pinhead square, and immature thrips counts at the 2 and 4 leaf stage and nodes above white flower as affected by planting date[ab].

Planting Date	Stand Count at 14 DAP[c]	Immature Thrips at 2 leaf	Immature Thrips at 4 leaf	Plant Height at Pinhead Square	NAWF[d]
	--plants ha^{-1}--	------------- #	-------------	--- cm ---	--- # ---
Mid-April	87,932 b	3 d	44 c	33 c	8.1 a
Mid- May	108,433 a	22 c	85 b	31 d	7.6 b
Late May	105,222 a	76 a	225 a	36 b	8.1 a
Mid- June	111,891 a	35 b	54 c	37 a	7.7 b

[a] Data were pooled over variety and PRE herbicides as no interactions were observed.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.
[c] Days after planting.
[d] Nodes above white flower

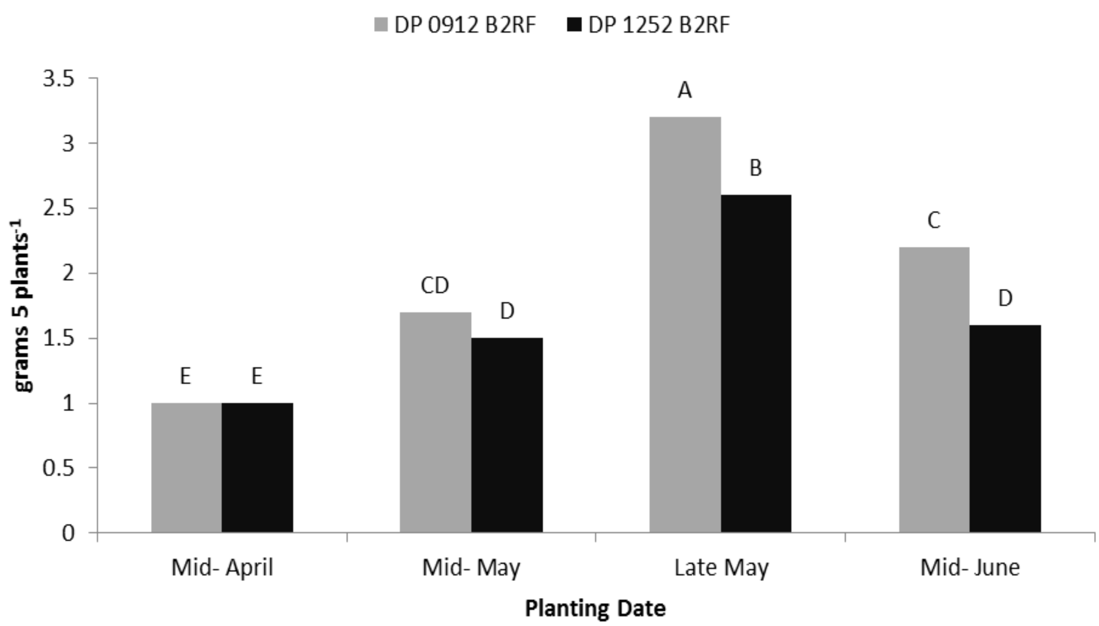

Figure 2.1 Cotton biomass at the 2 leaf stage as affected by an interaction between planting date and variety.

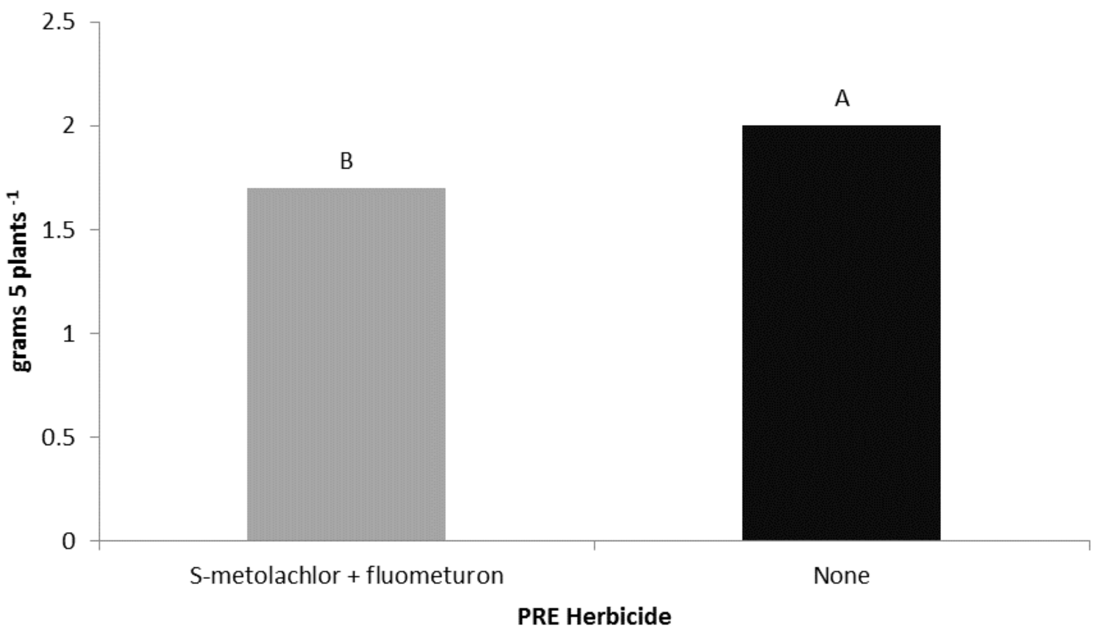

Figure 2.2 Cotton biomass at the 2 leaf stage as affected by PRE herbicides.

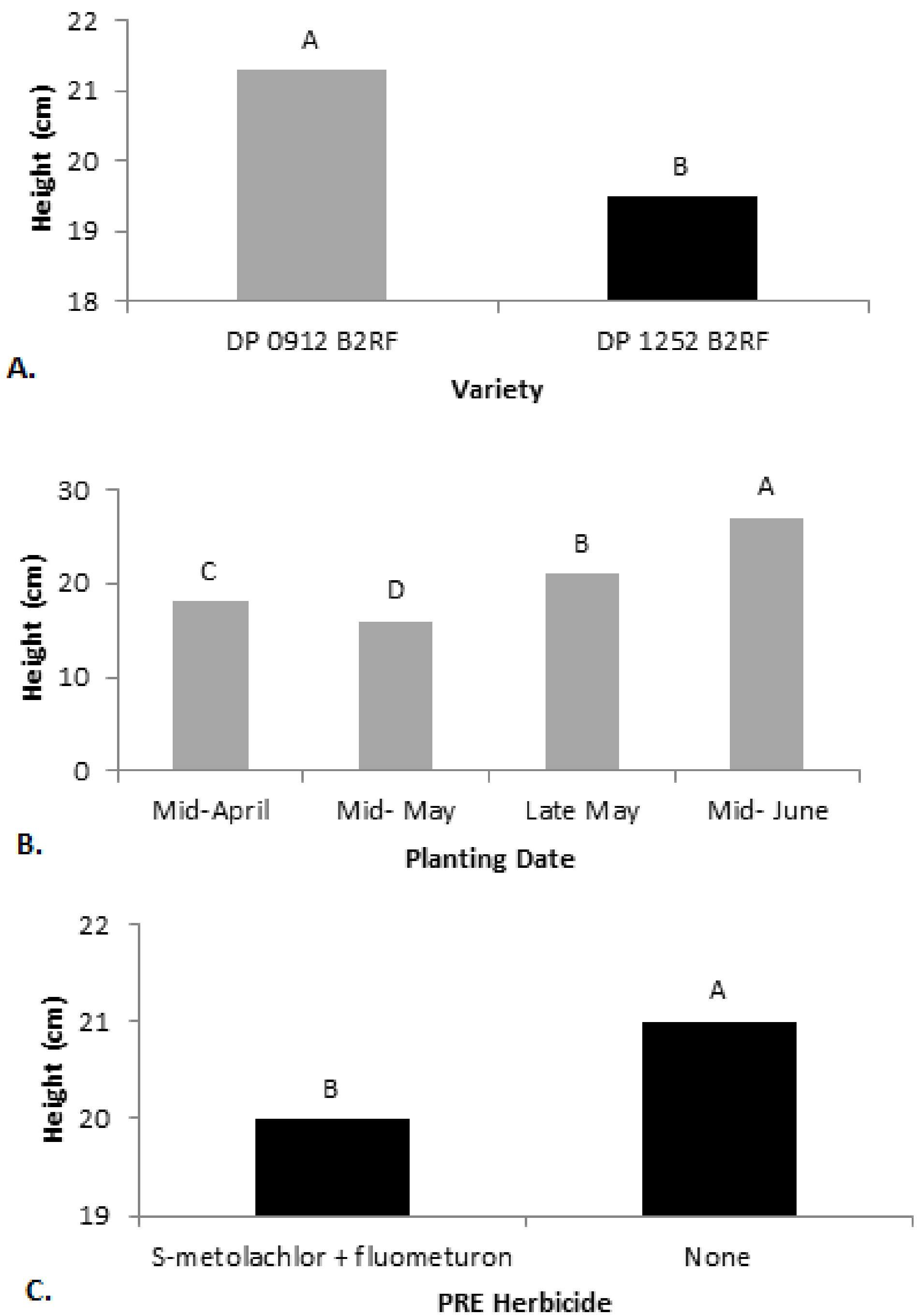

Figure 2.3 Cotton height at the 4 leaf stage.

As affected by variety (A.), planting date (B.), and PRE herbicide (C.) pooled over environment.

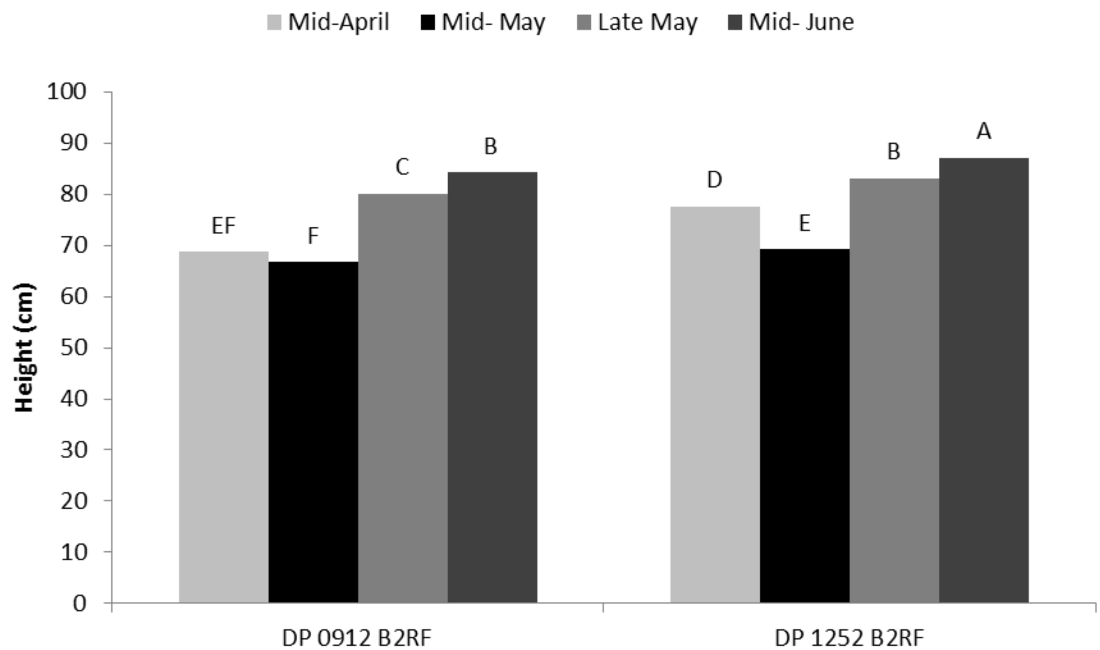

Figure 2.4 Cotton height at first bloom.

Table 2.4 Nodes above cracked boll and lint yield as affected by an interaction between variety and planting date[ab].

Variety	Planting Date	NACB[c]	Lint Yield
		—— # ——	-- kg ha^{-1} --
DP 0912 B2RF	Mid-April	1.9 d	2294 abc
	Mid- May	2.0 d	2238 ab
	Late May	4.9 b	2195 bc
	Mid- June	--	1494 d
DP 1252 B2RF	Mid-April	2.4 d	2352 ab
	Mid- May	3.8 c	2429 a
	Late May	6.2 a	2137 c
	Mid- June	--	1166 e

[a] Data were pooled across PRE herbicide as no interactions were observed.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.
[c] Nodes above cracked boll.
--NACB not present at the time of harvest aid application.

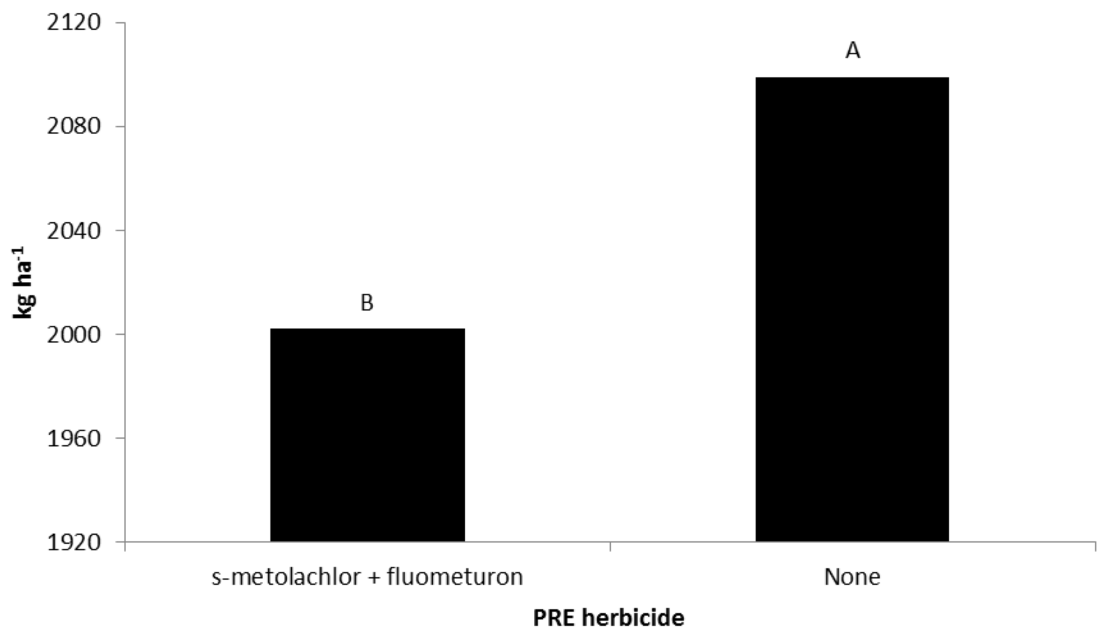

Figure 2.5 Cotton lint yield as affected by PRE herbicide.

References

Adams, B., A. Catchot, J. Gore, D. Cook, F. Musser, and D. Dodds. 2013. Impact of planting date and varietal maturity on tarnished plant bug in cotton. *J. Econ. En.* 106(6): 2378-2383

Askew, S.D., J.W. Wilcut, and J.R. Cranmer. 2002. Cotton (*Gossypium hirsutum*) and Weed Response to Flumioxazin Applied Preplant and Postemergence Directed. *Weed Tech.*16(1): 184-190.

Berger, S., J. Ferrell, B. Brecke, W. Faircloth, and D. Rowland. 2012. Influence of Flumioxazin Application Timing and Rate on Cotton Emergence and Yield. *Weed Technology*. 26(4):622-626.

Bibro, J.D.and L.L. Ray. 1973. Effect of Planting Date on the Yield and Fiber Properties of Three Cotton Cultivars. *Agron. J.* p. 606- 609

Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main- stem node counts. *J. Prod. Agric.*5: 532- 538.

Burris, E., A. M. Pavloff, B. R. Leonard, J. B. Graves, G. Church. 1990. Evaluation of two procedures for monitoring populations of early season insect pests (Thysanoptera: Thripidae and Homoptera: Aphids) in cotton under selected management systems. *J. Econ. Entomol.* 83: 1064–1068

Burris, E., K.J. Ratchford, A.M. Pavloff, D.J. Boquet, B.R. Williams. 1989. Thrips on seedling cotton: Related problems and control. *Louisiana Agricultural Experiment Station* Bulletin 811.

Carmer, S.G., W.E. Nyquist, And W.M. Walker. 1989. Least significant differences for combined analysis of experiments with two – or three factor designs. *Agron. J.* 81: 655-672.

Catchot, A., B. Adams, C. Allen, J. Bibb, D. Cook, D. Dodds, J. Gore, R. Jackson, B. Von Kanel, E. Larson, B. Layton, R. Luttrell, F. Musser. 2013. Insect Management Guide for Agronomic Crops 2013. *Mississippi State University Extension Service*. Publication 2471.

Chaudhry, M.R., A. Guitchounts. 2003. Cotton Facts. Common Fund for Commodities Technical paper No. 25: pp. 35-83

Cook, D., A. Herbert, D.S. Akin, J. Reed. 2011. Biology, Crop Injury, and Management of Thrips (Thysanoptera: Thripidae) Infesting Cotton Seedlings in the United States. *J. Pest. Mgmt.* B1-B9

Cook, D.R., B.R. Leonard, E. Burris, J. Gore. 2013. Impact of Thrips Infesting Cotton Seedlings on Cotton Yield Distribution and Maturity. *J. Cot. Sci.* 17:23-33.

Culpepper, A.S. 2009. Herbicide resistance impacting cotton production. p.93. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 8-11. 2009. Natl. Cotton Counc. Am., Memphis, TN.

Davidonis, G.H., A.S. Johnson, J.A Landivar, Carlos J. Fernanadez. 2004. Cotton Fiber Quality is Related to Boll Location and Planting Date. *Agron. J.* 16(1): 42-47

Dodds, D.M., A.L. Catchot, and J. Gore. 2011. 2011 cotton Maturity Guide. *Mississippi State University Extension Service, Mississippi State, MS*. Publication No.2697.

Dodds, D.M., J.C. Banks, L.T. Barber, R.K. Boman, S.M. Brown, K.L. Edminsten, J.C. Faircloth, M.A. Jones, R.G. Lemon, C.L. Main, C.D. Monks, E.R. Norton, A.M. Stewart, and R.L. Nichols. 2010. Beltwide Evaluation of Commercially Available Plant Growth Regulators. *J. Cot. Sci.* 14: 119-130.

Edmisten, K. 1993. Plant Monitoring: The Bloom Period. *Carolina Cotton Notes*. CCN-93-6b.

Everman, W.J., S.B. Clewis, A.C. York, J.W. Wilcut. 2009. Weed control and yield with flumioxazin, fomesfaen, and *s*-metolachlor systems for glufosinate-resistant cotton residual weed management. *Weed Tech.*23: 391-397.

Ferrell, J.A., G.E. MacDonald, R.Leon. 2012. Weed Management in Cotton. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication SS-AGR-04.

Ikram, R.M., N.A. Nadeem, A. Tanveer A, M. Yasin, A.U. Mohsin, R.N. Abbas, H. Rehman , M. Sibtain, M. Irfan. 2012. Comparative Efficacy of Different Pre-emergence Herbicides in Controlling Weeds in Cotton (*Gossypium hirsutum* L.). *Pakistan J. Weed Sci. Res.* 18(2): 209- 222

Irby, J.T., D. Reynolds, D. Dodds, A. Mills, C. Smith. 2010. Use of Acetochlor for Palmer Amaranth Control in Cotton. p. 1528-1528. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-7 Jan. 2010. Natl. Cotton Counc. Am., Memphis, TN

Kendig, J.A., R.L. Nichols, G.A. Ohmes. 2007. Tolerance of Cotton (*Gossypium hirsutum*) Seedlings to Preemergence and Postemergence Herbicides with Four Modes of Action. Plant Management Network. http://www.plantmanagementnetwork.org. Accessed 28 August 2014.

Kittock, D.L., B.B. Taylor, W.C. Hofmann. 1987. Partitioning Yield Reduction for Early Cotton Planting. *Crop Sci.* 27(5): 1011-1015

Layton, B. and J.T. Reed. 2002. Biology & Control of Thrips on Seedling Cotton. *Mississippi State University Extension Service*. Publication 2302.

Lingenfelter, D.D., N.L. Hartwig. 2007. Introduction to Weeds and Herbicides. *Pennsylvania State University*. Publication UC175

Luttrel, R.G. 1994. Cotton Pest Management: part 2 A. U.S. perspective. *Annual Review of Entomology*. 39; 527-542.

Main, C.L., J.C. Faircloth, L.E. Steckel, A.S. Culpepper, A.C. York. 2012. Cotton tolerance to fomesafen applied preemergence. *J.Cot. Sci.*(16): 80-87.

Morsello, S.C., R.S. Groves, B.A. Nault, G.G. Kennedy. 2008. Temperature and Precipitation Affect Seasonal Patterns of Dispersing Tobacco Thrips, *Frankliniella fusca,* and Onion Thrips, *Thrips tabaci* (Thysanoptera: Thripidae) Caught on Sticky Traps. *Env. Ent.* 37 (1): 79-86

Pettigrew, W.T. 2002. Improved Yield Potential with an Early Planting Cotton Production System. *Agron. J.* 94(5): 997-1003

Pettigrew, W.T. and W.R. Meredith Jr. 2009. Seed quality and Planting Date Effects on Cotton Lint Yield, Yield Components, and Fiber Quality. *J. Cot. Sci.* (13): 37- 47.

Reisig, D., D.A. Herbert, S. Malone. 2012. Impact of Neonicotinoid Seed Treatments on Thrips (Thysanoptera: Thripidae) and Soybean Yield in Virginia and North Carolina. *J. Econ. Entomol.* 105(3): 884-889.

Stewart, S., S.D. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R. Jackson, D. Kerns, B.R. Leonard, G. Lorenz, S. Micinski, D. Reisig, P. Roberts, G. Stude Baker, K. Tindall, and M. Toews. 2013. Survey of Thrips Species Infesting Cotton across the Southern U.S. Cotton Belt. *J. Cot. Sci.* 17(2): 1-7.

Telenko, D. and M. Donahoe. 2014. 2013 Evaluation of Non- irrigated Early- Maturing Cotton Varieties in Jay, Florida. *Institute of Food and Agricultural Sciences*. Publication SS-AGR-373.

Williams, M.R. 2013. Cotton Insect Losses 2012. p.546-586. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 7-10 Jan. 2013. Natl. Cotton Counc. Am., Memphis, TN.

Wrather, J., B. Phipps, W. Stevens, A. Phillips, E.D. Vories. 2008. Cotton Planting Date and Plant Population Effects on Yield and Quality in the Mississippi Delta. *J. Cot. Sci.*12(1):1-7.

Wumbei, A. 2014. The Effect of Date of Planting on the Performance of Promising Cotton Varieties. *J. Env. and Earth Sci.*. ISSN 2224-3216. 4(4): 1-9.

CHAPTER III

EVALUATION OF PRE HERBICIDES AND SEED TREATMENT ON THRIPS INFESTATION AND COTTON GROWTH, DEVELOPMENT, AND YIELD

Abstract

The increased use of preemergence (PRE) herbicides may result in decreased early season cotton growth and vigor which may exacerbate injury from thrips. Research was conducted in 2013 and 2014 at the Black Belt Branch Experiment Station near Brooksville, MS; at the R.R. Foil Plant Science Research Center near Starkville, MS; and at the Delta Research and Extension Center in Stoneville, MS to evaluate the impact of PRE herbicides and insecticide seed treatments on thrips infestations in cotton. DP 0912 B2RF was treated with thiamethoxam + fungicide, imidacloprid + fungicide, and fungicide only. All cotton seed was base treated with metalaxyl, pyraclostrobin, and fluxapyroxad. Preemergence herbicides included fluometuron at 1.12 kg ai ha^{-1}, diuron at 1.12 kg ai ha^{-1}, fomesafen at 0.28 kg ai ha^{-1}, *S*-metolachlor at 1.07 kg ai ha^{-1}, *S*-metolachlor at 1.07 kg ai ha^{-1}+ fluometuron at 1.12 kg ai ha^{-1}, as well as an untreated check. Injury from thrips was less prevalent on cotton seed treated with imidacloprid. Immature thrips counts at the four-leaf stage were greatest from cotton grown from seed treated with thiamethoxam which had 136 thrips per five plants. Preemergence herbicides did not impact thrips infestations at two- or four- leaf growth stage Cotton seed treated with imidacloprid resulted in taller plants throughout the growing season. Cotton heights

at first bloom were reduced when fluometuron or fomesafen were applied PRE. Seed treatments that lacked an insecticide resulted in delayed maturity. No significant differences in lint yield were present due to PRE herbicide. Seed treatments that included imidacloprid resulted in 80 kg ha^{-1} more lint than cotton grown from seed treated with thiamethoxam.

Introduction

Early season cotton (*Gossypium hirsutum* L.) growth is often inhibited by cool temperatures, wet soil conditions and seedling disease. When seedling cotton growth is delayed, thrips damage may be intensified (Layton and Reed 2002). Cotton may compensate for early season thrips injury; however high levels of thrips infestations may result in yield loss (Roberts and Rechel, 1996; Reed and Jackson 2002; Cook et al. 2011). Slow seedling cotton growth due to inclement weather conditions is conducive for thrips development and subsequent injury. Delaying early season cotton crop maturity extends the period for susceptibility to injury from thrips and other insect pests which may result in higher production costs (Stewart et al. 2013). Thrips infestations can create yield reductions of 10 to 304 kg ha^{-1} of lint (Layton and Reed 2002). Tobacco thrips (*Frankliniella fusca* [Hinds]) make up the majority of thrips species found on seedling cotton throughout the mid-south (Reed and Jackson 2002; Cook et al. 2003; Stewart et al. 2013). In Mississippi, tobacco thrips caused yield loss of 5,057 bales in 2012 (Stewart et al. 2013; Williams 2013).

Thrips control is often attained through use of prophylactic at-planting insecticide seed treatments (Cook et al. 2011). Historically, thrips control has been achieved with aldicarb or in-furrow insecticides such as acephate or seed treatments including acephate, thiamethoxam, and imidacloprid (Graham et al. 1995; Layton and Reed 2002; Reed and Jackson 2002; Cook et al. 2011; Stewart et al. 2013). The production of aldicarb compounds was terminated in 2010, and cotton growers have adopted the use of neonicotinoid seed treatments (Anonymous 2010; Stewart et al. 2013). Thiamethoxam and imidacloprid, have both proven to increase cotton yields by 15 to 20%, respectively, when compared to untreated cotton (Reed and Jackson 2002). Greene et al. (2002) found that thiamethoxam provided the greatest thrips control in inclement weather conditions, in conjuntion with dense thrips populations. Additional research has shown imidacloprid significantly decreased thrips numbers and injury which resulted in significantly greater cotton yields compared to cotton grown without an insecticide seed treatment (Graham et al. 1995).

Residual activity of neonicotinoid seed treatments ranges from two to four weeks after planting. Thiamethoxam has been shown to provide 21 to 45 days of insect protection from rates ranging from 105 to 350 g ai 100kg^{-1} seed (Maienfisch et al. 2001). Graham et al. (1995) observed up to 29 days of thrips control with imidacloprid. Although, thiamethoxam and imidacloprid have been shown to be effective for thrips control, supplemental foliar applications may be necessary for thrips control where heavy populations infest seedling cotton (Rummel et al. 1988; Stewart et al. 2013). The vast majority of Mississippi cotton growers plant seed with an insecticidal seed treatment (IST) for early season pests. Typically, one supplemental foliar application has been required on 25% of total cotton hectares has been required to control thrips (Willams, 2012). In 2011, thrips became the third most injurious pest in cotton across the Cotton Belt (Williams, 2012). In 2012, 80% of Mississippi cotton hectares required at least two supplemental sprays for thrips control, costing growers on average \$41.77 ha^{-1} (Williams 2013). The increase in foliar applications indicates that there is a potential loss of thrips control from neonicotinoid insecticidal seed treatments used in Mississippi. In addition, continued expansion of glyphosate-resistant (GR) Palmer amaranth (*Amaranthus palmeri* [S. Wats.]) in Mississippi has necessitated use of preemergence (PRE) residual herbicides (Culpepper et al. 2006; Heap 2008).

Due to its prolific reproductive capabilities and intensive management required to prevent yield loss, GR Palmer amaranth is the leading concern in weed management for cotton producers across the Cotton Belt (Culpepper et al. 2010; Culpepper and Steckel, 2010; Webster 2014). Glyphosate-resistant Palmer amaranth and other troublesome weeds have forced cotton growers to use PRE herbicides to achieve adequate weed control (Culpepper 2009). Residual herbicides are used early in the season to provide residual control needed due to the slow growth habit of seedling cotton (Buchanan 1992; Colquoun 2006). Cotton requires up to eight weeks of early season weed control to achieve maximum yields (Buchanan and Burns, 1970; Buchanan 1992). The absence of a PRE herbicide within a weed control system has shown to significantly reduce yields (Everman et al. 2009).

Early season cotton growth can be delayed by cool temperatures, high soil moisture, insects, nutrient deficiencies, and seedling diseases (Chaundhry and Guitchounts 2003). These factors are often confused with or attributed to herbicide injury (Lingenfelter 2007). Preemergence herbicide injury has been reported in seedling cotton (Kendig et al. 2007; Main et al. 2012). Commonly used herbicides such as fomesafen, *S*-metolachlor, diuron, and fluometruon, are labeled PRE in cotton, but can cause injury if not used according to label directions or if environmental conditions are not favorable (Anonymous 2014a; 2014b; 2014c; 2014d). Necrosis on cotton has been observed from both fomesafen and diuron applied PRE (Cahoon et al. 2014). In addition, early season cotton stress due to necrosis from fomesafen resulted in up to 25% yield reduction (Main et al. 2012).

Many factors contribute to the severity of thrips injury to seedling cotton. Factors such as environmental conditions, PRE herbicide injury, and choice of thrips control options can all influence the damage caused by thrips. Essentially, all cotton seed in Mississippi is pretreated with imidacloprid or thiamethoxam insecticide for thrips control. Preemergence herbicide use in cotton has increased due to GR weeds and early season herbicide injury and inclement weather conditions can exacerbate thrips infestations an injury to seedling cotton. Therefore this research was conducted to determine potential interaction between PRE herbicides and IST. Given the extensive use of both PRE herbicides and ISTs, it is critical to determine the response of seedling cotton to PRE herbicides and ISTs in order to minimize potential cotton injury and maximize yield potential.

Materials and Methods

Studies were conducted at the R.R. Foil Plant Science Research Center in Starkville, MS; at the Mississippi State University Delta Research and Extension Center in Stoneville, MS; and at the Black Belt Branch Experiment Station near Brooksville, MS in 2013 and 2014 to determine the impact of insecticide seed treatment and PRE herbicide on thrips infestations in cotton. Treatments were arranged in a two-factor factorial arrangement of treatments within a randomized complete block design with four replications. Factor A consisted of insecticide seed treatment and factor B consisted of PRE herbicide. Three insecticidal seed treatments (IST) were utilized in this experiment. Cotton seed were treated with thiamethoxam, imidacloprid, and no IST. All seeds were treated with metalaxyl, pyraclostrobin, and fluxapyroxad to minimize the effect of seedling disease. Once seed were treated, samples from each treatment were analyzed using high performance liquid chromatography (HPLC) to confirm the amount of active ingredient for each compound on the seed. Seed treatments with amounts applied and detected by HPLC analyses are shown in Table 3.2. The following preemergence (PRE) herbicides were utilized in this study: fluometuron (Cotoran 4L- Makhteshim Agan of North America, Raleigh, NC) at 1.12 kg ai ha^{-1}, *S*-metolachlor (Dual Magnum- Synegenta Crop Protection, Greensboro, NC) at 1.07 kg ai ha^{-1}, diuron (Direx 4L- Makhteshim Agan of North America, Raleigh, NC) at 1.12 kg ai ha^{-1}, fomesafen (Reflex- Synegenta Crop Protection, Greensboro, NC) at 0.28 kg ai ha^{-1}, a combination of *S*-metolachlor at 1.07 kg ai ha^{-1} + fluometuron 1.12 kg ai ha^{-1}, and an untreated check. In both years, PRE herbicides were applied in a delivery volume of 140 L ha^{-1} with CO_2 powered backpack or tractor mounted compressed sprayer. Activating rainfalls were received within 24 hours after planting at each location both years.

Soil textures, cotton planting dates, application equipment, and harvest dates at each location are given in Table 3.1. In 2013, DP 0912 B2RF (Monsanto Company, St. Louis, MO) was planted at 123,500 seeds ha^{-1} on 15 May at Starkville, 15 May at Stoneville, and 20 May at Brooksville location. In 2014, the same variety was seeded at the following dates: on 07 May at Starkville, and 08 May at Stoneville location. Soils were classified as follows: a Brooksville silty clay at Brooksville; Leeper silty clay loam at Starkville; a Bosket very fine sandy loam at Stoneville. At Starkville and Brooksville, plots consisted of 4- 97 cm rows 12.2 m in length and 4- 102 cm rows 12.2 m in length in Stoneville. The cotton variety used expressed two *Bt* genes to eliminate potential yield loss from lepidopteran pests.

Furrow irrigation was utilized at the Starkville and Stoneville locations while Brooksville was grown under dry land conditions. All plots were maintained weed free throughout the growing season using glyphosate and hand weeding. A total of 134 kg N ha^{-1} was applied in split applications at all locations in both years. The initial application was made following planting and the second application was made approximately 35 days after planting. All other fertilizer was applied based on soil test recommendations at each location. All plant growth regulators, insecticides (except those for thrips), and harvest aids were applied based on Mississippi State University Extension Service recommendations (Anonymous 2014e; Catchot et al. 2014).

Data collection included the following: stand counts, visual thrips injury ratings, cotton biomass, and thrips populations at 14 DAP (days after planting) and 28 DAP; cotton height at 28 DAP; cotton height, total nodes, and nodes above white flower at first bloom; and cotton height, total nodes and nodes above cracked boll (NACB) at harvest; and lint yield.

Cotton heights were collected by measuring from the soil level to the apical meristem. Thrips injury ratings ranged from 0 to 5 with 0 being absence of injury and 5 being dead plant. Cotton biomass was collected from five randomly selected plants from each plot with each plant cut at the soil surface, placed into paper bags, and air dried in a forced air dryer for 72 hours at 70°C. After drying, cotton plants were weighed on an analytical balance to determine dry weight biomass. Thrips populations were sampled using the whole plant technique and washed using a technique modified from that of Burris et al. (1989; 1990). Five plants were selected randomly from each plot and clipped below the cotyledon leaves and quickly placed into self-sealing bags. The bags were brought to the laboratory and filled with a solution containing 10% bleach and soap. Cotton plants were allowed to soak in bleach and soap solution for 20 minutes. Plants were then washed over a standard No. 100 Sieve. Thrips were then separated from the sieve using an alcohol solution in a 500 ml squirt bottle onto 9-cm white filter paper marked with gridlines (Reisig et al. 2012). Filter paper was then placed into petri dishes from which thrips were identified and counted using microscopy. Adult thrips that were dark in color were considered tobacco thrips while lighter colored adult thrips were considered other species. Stewart et al. (2013) observed 98% of thrips in MS were tobacco thrips. All immatures and adult tobacco thrips were counted. Nodes above weight flower (NAWF) were determined by counting the number of nodes on the main stem from the uppermost first position white flower to the uppermost leaf that was the size of a quarter (Bourland et al. 1992). Nodes above cracked boll (NACB) were determined by counting the number of nodes above the uppermost first position cracked boll to the uppermost first position harvestable boll. The center two rows of each plot were harvested using a cotton picker modified for small plot research. Lint yield for each plot was calculated from lint percent obtained from ginning each individual plot sample. Data were subjected to analysis of variance using the PROC MIXED procedure of SAS v. 9.3 (SAS institute; Cary, NC). Means were separated using Fisher's Protected LSD ($\alpha \leq 0.05$). With interest in interactions between seed treatment and PRE herbicide, data were analyzed with fixed effects including environment, PRE herbicide, seed treatment, and all interactions. The only factor that had a significant environment, PRE herbicide, and seed treatment interaction was cotton height at first bloom; therefore, data was presented by environment. Data were pooled across environments to allow for inferences of treatments over a range of environments for all other variables (Carmer et al. 1989). Degrees of freedom were calculated using the Kenward-Roger method.

Results and Discussion

Immature thrips counts were affected by seed treatment at both the two- and four-leaf growth stages (Table 3.3). Similar to Clarkson et al. (2013), no significant effects from PRE herbicide were observed with respect to number of immature thrips present at each cotton growth stage. Immature thrips at the two-leaf stage ranged from 22 to 85 thrips per five plants (Table 3.4). Cotton seed treated with imidacloprid had fewer immature thrips at the two-leaf stage (22) than cotton grown from seed treated with thiamethoxam (31) or fungicide only (85) (Table 3.4). Cotton seed treated with thiamethoxam resulted in significantly less immature thrips in two-leaf cotton (31) than the fungicide alone (85). Cotton seed treated with thiamethoxam had significantly more immature thrips than cotton grown from seed treated with fungicide only at the four- leaf stage (Table 3.4). Cotton seed treated with thiamethoxam resulted in 136 immature thrips per five plants whereas cotton seed treated with fungicide only had 115 immature thrips per five plants. However, cotton seed treated with imidacloprid had 93 immature thrips per five plants at the four-leaf stage which was significantly lower thrips present on cotton grown from seed treated with fungicide only (115). These findings disagree with

Greene et al. (2002) who found cotton seed treated with thiamethoxam resulted in lower thrips numbers when compared to imidacloprid.

Visual thrips damage at the two-leaf growth was affected by seed treatment and PRE herbicide (Table 3.3). Cotton seed treated with imidacloprid resulted in less visual thrips injury than cotton seed treated with thiamethoxam and fungicide only (Table 3.4). Cotton seed treated with fungicide only resulted in significantly more visual thrips damage than cotton seed treated with thiamethoxam. Furthermore, cotton treated with fluometuron and fomesafen PRE had significantly greater thrips injury at the two- leaf stage than cotton treated with *S*- metolachlor as weel as the untreated check (Figure 3.1). However, visual thrips damage on cotton treated with fluometuron and fomesafen was not significantly different than visual thrips damage on cotton treated with diuron or the combination of fluometuron and *S*-metolachlor. Insecticide seed treatment had a significant effect on visual thrips damage at the four-leaf stage. Cotton seed treated with fungicide only resulted in more thrips injury than cotton seed treated with thiamethoxam and imidacloprid (Table 3.4). Additionally, cotton seed treated with thiamethoxam had more thrips injury than cotton seed treated with imidacloprid.

Insecticide seed treatment and PRE herbicide had no significant effect on stand counts at 14 DAP (Table 3.3). Stand counts averaged 110,000 to 114,000 plants ha^{-1}; however, stand counts 28 DAP were significantly impacted by insecticide seed treatment. Cotton seed treated with imidacloprid and thiamethoxam resulted in significantly greater stand counts 28 DAP than cotton seed treated with fungicide only (Table 3.4). Additionally, overall stand counts were reduced from 14 to 28 DAP. Immature thrips populations also increased from the 2 to 4 leaf stage. Immature thrips populations, along with other factors, were potentially a compounding factor in the stand loss from 14 to 28 DAP (Table 3.4).

Insecticide seed treatment significantly affected cotton biomass at the four-leaf growth stage (Table 3.3). Cotton biomass at the four leaf stage ranged from 3.8 to 5.1 grams per five plants. Cotton seed treated with imidacloprid produced plants with more biomass (5.1 grams) when compared to cotton seed treated with thiamethoxam (4.7 grams) and fungicide only (3.8 grams) (Figure 3.2). Thiamethoxam seed treatment resulted in cotton with significantly more mass than cotton grown from seed treated with fungicide only. Cotton seed treated with imidacloprid resulted in less thrips infestation and visual injury symptomology than cotton grown from seed treated with thiamethoxam and fungicide only. Differences in thrips infestations and injury likely impacted cotton biomass. Results are similar to Clarkson et al. (2013) who observed cotton seed treated with imidacloprid produced more vigorous plants.

An interaction between seed treatment and PRE herbicide was observed for plant heights at first bloom at Brooksville and Stoneville in 2013 (Table 3.5). At Brooksville in 2013, cotton seed treated with fungicide only was shorter than cotton seed treated with imidacloprid and thiamethoxam at first bloom regardless of PRE herbicide applied (Figure 3.3). However, when fomesafen was applied PRE, cotton grown from seed treated with thiamethoxam was shorter than cotton grown from seed treated with imidacloprid. Also, when *S*-metolachlor was applied PRE, cotton grown from seed treated with thiamethoxam was taller than cotton grown from seed treated with imidacloprid (Figure 3.3). Generally, at Stoneville in 2013, cotton grown from seed treated with fungicide only was shorter than cotton grown from seed treated with thiamethoxam and imidacloprid. However, when fomesafen was applied PRE, cotton grown from seed treated with thiamethoxam and imidacloprid was shorter at first bloom than cotton grown from seed treated with fungicide only (Figure 3.4). Also, when fluometuron + *S*-metolachlor were applied PRE, and cotton was seed treated with imidacloprid, no differences in cotton height at first bloom was observed. However, plant height of cotton grown from seed treated with thiamethoxam was significantly reduced and was similar to height of cotton grown from seed treated with fungicide only at first bloom (Figure 3.4). Cotton heights at first bloom at Starkville 2013, Starkville 2014, and Stoneville 2014, were impacted by insecticidal seed treatment (data not shown). Cotton grown from seed treated with imidacloprid was significantly taller than cotton grown from seed treated with thiamethoxam or fungicide only at first bloom in Starkville 2013 whereas cotton grown from seed treated with thiamethoxam was taller than cotton grown from seed treated with fungicide only. In Starkville 2014 and Stoneville 2014, cotton grown from seed treated with imidacloprid and thiamethoxam were similar, but significantly taller than cotton grown from seed treated with fungicide only at first bloom (data not shown). Cotton heights at first bloom in Starkville 2013 were affected by PRE herbicide (data not shown). Cotton untreated or applied with *S*- metolachlor + fluometuron PRE were significantly taller than cotton where diuron or fomesafen was applied PRE. However, cotton treated with *S*- metolachlor or fluometuron had similar heights compared to cotton untreated or *S*- metolachlor + fluometuron were applied PRE.

Insecticide seed treatment and PRE herbicide significantly impacted NAWF counts at first bloom (Table 3.3). Cotton grown from seed treated with thiamethoxam had higher NAWF counts than cotton grown from seed treated with imidacloprid and fungicide only (Table 3.6). Lower NAWF counts indicate stressful growing conditions (Edmisten, 1993). Cotton grown from seed treated with imidacloprid and fungicide only had similar NAWF counts. Cotton treated with fluometuron and fomesafen PRE had lower NAWF counts than cotton treated with fluometuron + *S*-metolachlor PRE as well as the untreated check (data not shown). Under normal growing conditions, nine to ten NAWF at first bloom is common (Edmisten, 1993).

Insecticide seed treatment significantly affected NACB immediately prior to harvest aid application (Table 3.3). Cotton grown from seed treated with fungicide only had significantly greater NACB counts than cotton grown from seed treated with imidacloprid and thiamethoxam (Table 3.6). Seed treated with insecticides resulted in similar NACB counts at the end of the year. Node above cracked boll counts are an indicator of plant maturity and a tool used to make harvest aid applications (Hake et al. 1996). Cotton seed treated with fungicide only resulted in a delay in maturity as compared to cotton grown from seed treated with an insecticide. Historical data shows that seed treatments lacking an insecticide and/or substantial thrips injury has potential to delay crop maturity (Cook et al .2011).

Insecticide seed treatment had an effect on lint yields; however, PRE herbicide was not significant (Table 3.3). Cotton lint yields ranged from 2434 to 2586 kg ha^{-1} depending on insecticide seed treatment applied. Cotton grown from seed treated with imidacloprid had greater yields (2586 kg ha^{-1}) than cotton grown from seed treated with thiamethoxam (2506 kg ha^{-1}) and fungicide only (2343 kg ha^{-1}) (Table 3.6). However, cotton seed treated with thiamethoxam yielded similar to cotton grown from seed treated with fungicide only. Seed treatments lacking an insecticide resulted in reduced yields compared to seed treatments that included an insecticide. These data agree with previous research suggesting significant yield increases with cotton seed treated with imidacloprid (Graham et al. 1995).

In conclusion, insecticidal seed treatments containing thiamethoxam displayed reduced thrips control in cotton compared to imidacloprid. Data from Darnell et al. (2015) has shown elevated LC50's for thrips exposed to thiamethoxam compared to thrips exposed to imidacloprid thrips populations collected in Mississippi. These data further indicated increased tolerance to thiamethoxam resulting in poor control, higher visual damage ratings, and reduced yield as observed in this study. However, interactions between PRE herbicide and insecticide seed treatment were not present for this study for reduced thrips control. Treatments that lack an efficacious insecticide seed treatment resulted in less vigorous cotton, higher thrips populations, and more visual thrips injury symptomology. Increased thrips control and more vigorous cotton plants were observed from cotton grown from seed treated with imidacloprid. Application of fomesafen PRE can negatively affect early season cotton vigor in conjunction with seed treatments that lack an effective insecticide or no insecticide at all. No reduction in lint yield was observed due to PRE herbicide application. However, differences in yield were observed due to seed treatments. Greater than 95% of all adult thrips collected throughout the study were tobacco thrips. Therefore, it should be assumed that reduced efficacy of thiamethoxam is specific to this species of thrips as other thrips species were not in present sufficient numbers to draw conclusions. Cotton seed treatments that contained imidacloprid resulted in greater yields than cotton grown from seed treatments containing thiamethoxam or fungicide only. Growers should avoid use of seed treatments containing thiamethoxam in cotton. Treatments containing imidacloprid will provide greater control; however, scouting and treating for thrips according to thresholds is critical even if insecticidal seed treatments are applied.

Table 3.1 Soil textures, cotton planting dates, PRE herbicide application dates, application equipment, and harvest dates for 2013 - 2014.

Environment	Soil Type	Planting Dates	Application Equipment	Spray Tip Nozzle	Application Volume	Pressure	Harvest Date
					— L ha^{-1} —	— kPa —	
Starkville	Leeper silty clay soil	15 May 2013	Tractor mounted compressed air sprayer	110015 AIXR	140	428	18 October 2013
		07 May 2014					7 October 2014
Stoneville	Bosket very fine sandy loam	15 May 2013	Tractor mounted compressed air sprayer	8002 XR	140	255	29 October 2013
		08 May 2014					21 October 2014
Brooksville	Brooksville silty clay	20 May 2013	CO_2- pressurized backpack sprayer	110015 TTI	140	317	29 October 2013

Table 3.2 Seed treatment active ingredients, formulation, rate, and amount detected per seed from HPLC.

Treatment	Active Ingredient	Rate	Formulation*	Amount detected per seed**
		— % —		— mg a.i.seed^{-1} —
Fungicide Only	Metalaxyl	28.4	SL	0.014
	Pyraclostrobin	18.4	FS	0.020
	Fluxapyroxad	28.7	FS	0.018
Imidacloprid + fungicide	Metalaxyl	28.4	SL	0.014
	Pyraclostrobin	18.4	FS	0.040
	Ipconazole	0.5 kg L^{-1}	FS	0.002
	Fluxapyroxad	28.7	FS	0.018
	Imidacloprid	48.7	FS	0.375
Thiamethoxam + fungicide	Metalaxyl	28.4	SL	0.014
	Pyraclostrobin	18.4	FS	0.040
	Ipconazole	0.5 kg L^{-1}	FS	0.002
	Fluxapyroxad	28.7	FS	0.018
	Thiamethoxam	0.6 kg L^{-1}	FS	0.375

* SL, Soluble concentrate for seed treatment; FS, Flowable concentrate for seed treatment
** Amount detected per seed through HPLC.

Table 3.3 Analysis of variance p-values for stand counts at 14 and 28 DAP[a]; immature thrips count at the 2 and 4 leaf growth stage, cotton biomass at 4 leaf, NAWF, NACB, and lint yield.

Source	Degrees of Freedom	Stand Counts 14 DAP[a]	Stand Counts 28 DAP[a]	Immature Thrips at 2 Leaf	Immature Thrips at 4 Leaf	Visual Thrips Damage at 2 Leaf	Visual Thrips Damage at 4 Leaf	Cotton Biomass at 4 leaf	NAWF[b]	NACB[c]	Lint Yield
Seed Treatment	2	0.3853	0.0129	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0139	<0.0001	0.0011
PRE Herbicide	5	0.9353	0.7546	0.2859	0.6953	0.0413	0.2676	0.4031	0.0048	0.1328	0.3325
Seed Treatment x PRE Herbicide	10	0.8154	0.9759	0.6886	0.6751	0.1821	0.6109	0.8853	0.2555	0.0511	0.2849

[a] Days after planting.
[b] Nodes above white flower.
[c] Nodes above cracked boll.

Table 3.4 Stand counts at 14 and 28 days after planting, and immature thrips counts and visual thrips damage at the 2 and 4 leaf growth stage, as affected by seed treatment[ab].

Seed Treatment	Stand Counts 14 DAP[c]	Stand Counts 28 DAP[c]	Immature Thrips at 2 Leaf	Immature Thrips at 4 Leaf	Visual Thrips Damage at 2 leaf	Visual Thrips Damage at 4 leaf
	—— plants ha^{-1} ——		———— # ————		—— (0-5)[d] ——	
Fungicide Only	110,409 a	104,975 b	85 a	115 b	2.9 a	3.4 a
Imidacloprid + Fungicide	114,262 a	112,138 a	22 c	93 c	1.9 c	2.0 c
Thiamethoxam + Fungicide	112,558 a	109,915 a	31 b	136 a	2.5 b	2.6 b

[a] Data were pooled over PRE herbicides as no interactions were observed.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$
[c] Days after planting.

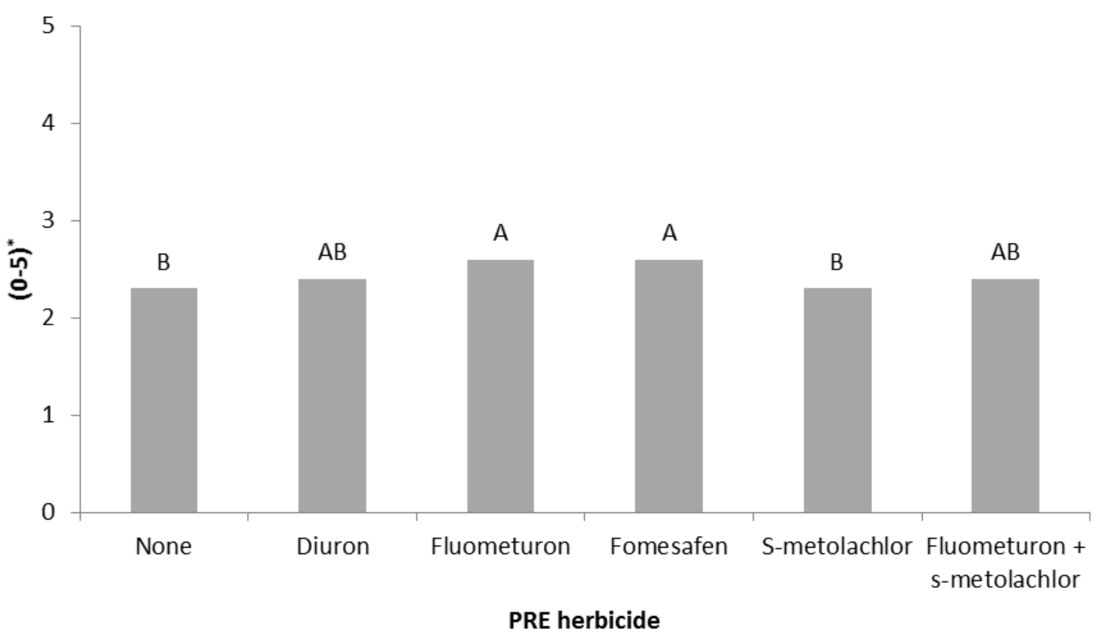

Figure 3.1 Visual thrips damage at the 2 leaf stage as affected by PRE herbicide.

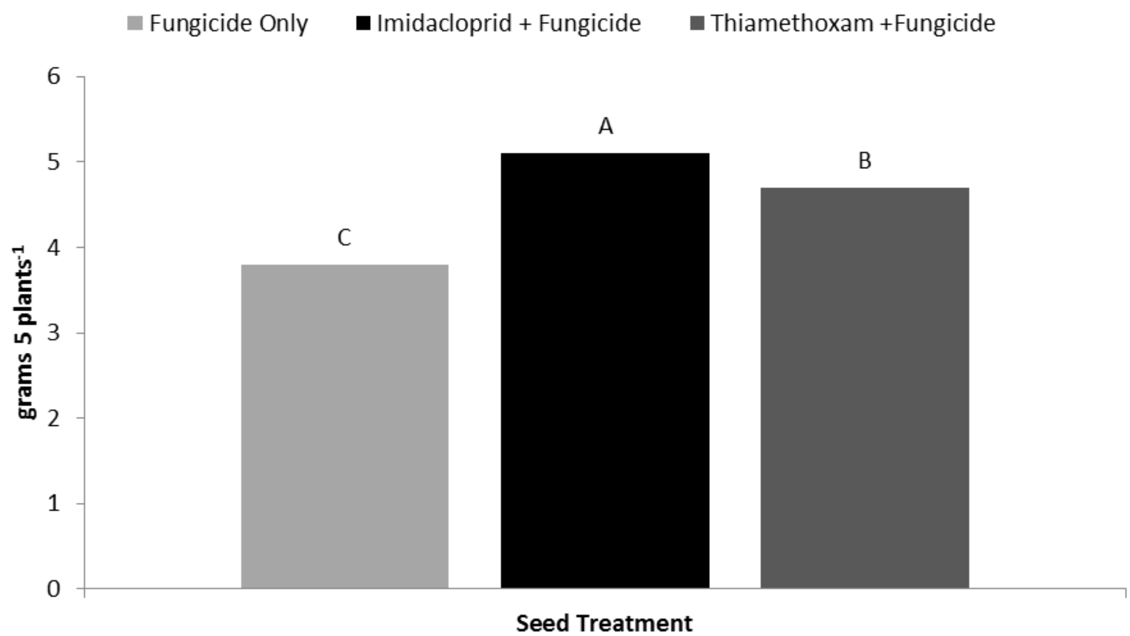

Figure 3.2 Cotton biomass at the 4 leaf stage as affected by seed treatment.

Table 3.5 Analysis of variance p-values for cotton height at first bloom as affected by an interaction between environment, seed treatment, and PRE herbicide[a*].

Source	Degrees of Freedom	Plant Heights at First Bloom*	Brooksville 2013	Starkville 2013	Stoneville 2013	Starkville 2014	Stoneville 2014
Seed Treatment	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
PRE Herbicide	5	<0.0001	0.0006	0.0034	<0.0001	0.0549	0.2821
Seed Treatment x PRE Herbicide	10	0.0165	0.0196	0.0851	0.0038	0.0532	0.5405

[a] Data were analyzed with ANOVA containing environment, seed treatment, and PRE herbicide as fixed effects.
[*] Data were analyzed with ANOVA containing seed treatment and PRE herbicide as fixed effects. Data were pooled across environments.

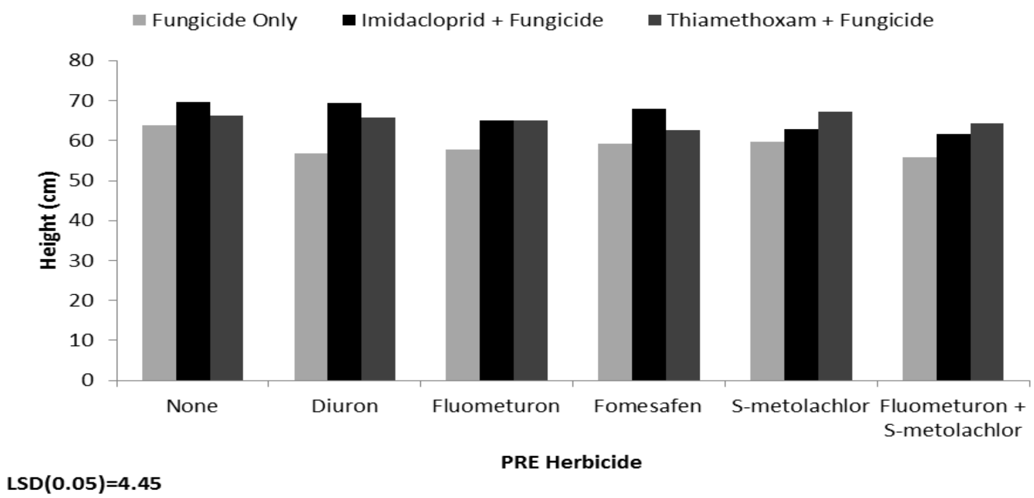

Figure 3.3 Cotton height at first bloom at Brooksville in 2013 as affected by an interaction between PRE herbicide and seed treatment.

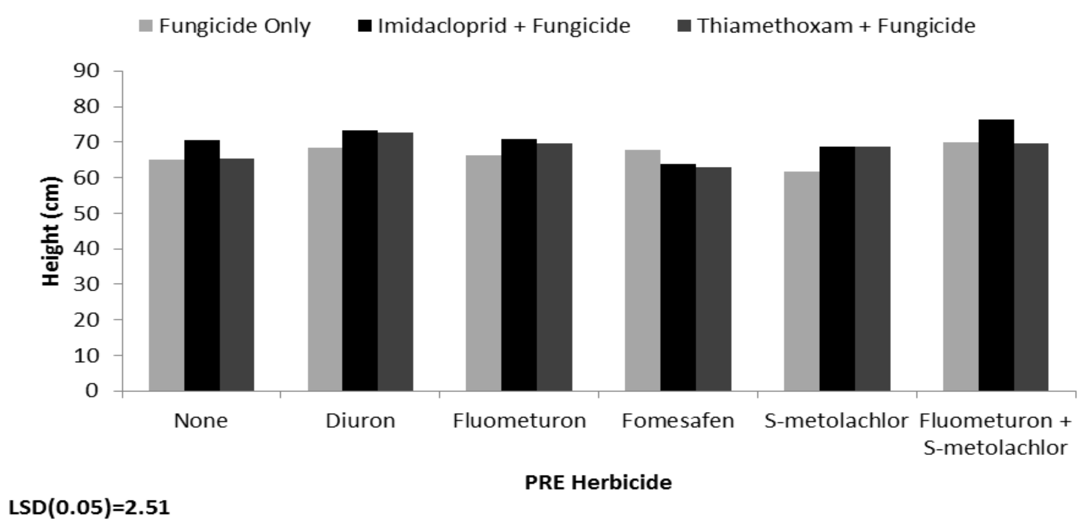

Figure 3.4 Cotton height at first bloom at Stoneville in 2013 as affected by an interaction between PRE herbicide and seed treatment.

Table 3.6 Nodes above white flower at first bloom, nodes above cracked boll prior to harvest, and lint yield as affected by seed treatment[ab]

Seed Treatment	NAWF[c]	NACB[d]	Lint Yield
	———— # ————		— kg ha^{-1} —
Fungicide Only	7.8 b	3.9 a	2434 c
Imidacloprid + Fungicide	7.8 b	3.4 b	2586 a
Thiamethoxam + Fungicide	8.0 a	3.5 b	2506 b

[a] Data were pooled across PRE herbicide as no interactions were observed.

[b] Means within a column followed by the same letter were not significantly different based on Fisher's protected LSD at p≤0.05

[c] Nodes above white flower.

[d] Nodes above cracked boll.

References

Anonymous. 2010. Agreement to Terminate All Uses of Aldicarb. *U.S. Environmental Protection Agency*. Available at http://www.epa.gov. Accessed 3 Dec. 2014.

Anonymous. 2014a. Reflex herbicide label. Available at http://www.cdms.ne.t (Verified 9 Sept. 2014).

Anonymous. 2014b. Cotoran herbicide label. Available at http://www.cdms.net. (Verified 9 Sept. 2014).

Anonymous. 2014c. Dual Magnum herbicide label. Available at http://www.cdms.net. (Verified 9 Sept. 2014).

Anonymous. 2014d. Direx herbicide label. Available at http://www.cdms.net. (Verified 9 Sept. 2014).

Anonymous. 2014e. Weed Control Guidelines for Mississippi. Mississippi State University Extension Service, Mississippi Agricultural and Forestry Experiment Station. Publication 1532.

Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main- stem node counts. *J. Prod. Agric.*5: 532- 538.

Buchanan, G.A. 1992. Trends in Weed Control Methods. *In* McWhorter, G.M., J.R. Abernathy (ed). Weeds of Cotton: Characterization and Control. p. 47-72.

Buchanan, G.A., and Burns E.R. 1970. Influence of weed competition on cotton. *Weed Sci.* 18: 149-154.

Burris, E., A. M. Pavloff, B. R. Leonard, J. B. Graves, G. Church. 1990. Evaluation of two procedures for monitoring populations of early season insect pests (Thysanoptera: Thripidae and Homoptera: Aphids) in cotton under selected management systems. *J. Econ. Entomol.* 83: 1064–1068

Burris, E., K.J. Ratchford, A.M. Pavloff, D.J. Boquet, B.R. Williams. 1989. Thrips on seedling cotton: Related problems and control. *Louisiana Agricultural Experiment Station* Bulletin 811.

Cahoon, C.W., A.C. York, D.L. Jordan, W.J. Everman, and R.W. Seagroves. 2014. An Alternative to Multiple Protoporphyrinogen Oxidase Inhibitor Applications in No-Till Cotton. *Weed Tech* 28(1): 58-71

Carmer, S.G., W.E. Nyquist, and W.M. Walker. 1989. Least significant differences for combined analysis of experiments with two – or three factor designs. Agron. J. 81: 655-672.

Catchot, A., C. Allen, D. Cook, D. Dodds, J. Gore, T. Irby, E. Larson, B. Layton, S. Meyers, F. Musser. 2014. InsectManagement Guide for Agronomic Crops 2014. Mississippi State University Extension Service. Publication 2471.

Chaudhry, M.R., A. Guitchounts. 2003. Cotton Facts. *Common Fund for Commodities Technical paper No. 25*: pp. 35-83

Clarkson, D.L., G.M. Lorenz, L.T. Barber, N.M. Tailon, B.C. Thrash, W.A. Plummer, M.E. Everett, and L.R. Orellana Jiminez. 2013. Impact of Pre- Emergence Herbicide Applications on Cotton with Selected Insecticide Seed Treatments. *Summaries of Arkansas Cotton Research*. pp.139-143.

Colquhoun, J. 2006. Herbicide persistence and carryover. University of Wisconsin-System Board of Regents and University of Wisconsin- Extension, Cooperative Extension. Publication A3819.

Cook, D., A. Herbert, D.S. Akin, and J.Reed. 2011. Biology, Crop Injury, and Management of Thrips (Thysanoptera: Thripidae) Infesting Cotton Seedlings in the United States. *J. Int. Pest Mgmt.* 2(2) pp. B1- B9.

Cook, D.R., C.T. Allen, E. Burris, B.L. Freeman, G.A. Herzog, G.L. Lentz, B.R. Leonard, and J.T. Reed. 2003. A survey of thrips (Thysanoptera) species infesting cotton seedlings in Alabama, Arkansas, Georgia, Louisiana, Mississippi, and Tennessee. *J. Ent. Sci.* (38) 669-681.

Culpepper, A.S. 2009. Herbicide resistance impacting cotton production. p. 93. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 2009. Natl. Cotton Counc. Am., Memphis, TN.

Culpepper, A.S., and L.E. Steckel. 2010. Value of Transgenic Crops- Weed Management. p. 6-7. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 5-7 Jan. 2010. Natl. Cotton Counc. Am., Memphis, TN.

Culpepper, A.S., T.L. Grey, W.K. Vencill, J.M. Kichler, T.M. Wedster, S.M. Brown, A.C. York, J.W. Davis, and W.W. Hanna. 2006. Glyphosate- resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. *Weed Sci.* 54: 620-626.

Culpepper, A.S., T.M Webster, L.M. Sosnoskie, A.C. York. 2010. Glyphosate- resistant Palmer amaranth in the United States. *Glyphosate Resistance in Crops and Weeds: History, Development, and Management*. pp. 195- 212.

Darnell, C., A. Catchot, F. Musser, D. Cook, J. Gore. Susceptibility of tabacco thrips, *Frankliniella fusca*, to the neonicotinoid class of insecticides in Mid-South region. *In Press* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-7 Jan. 2015. Natl. Cotton Counc. Am., Memphis, TN.

Edmisten, K. 1993. Plant Monitoring: The Bloom Period. *Carolina Cotton Notes*. CCN-93-6b.

Everman, W.J., S.B. Clewis, A.C. York, J.W. Wilcut. 2009. Weed control and yield with flumioxazin, fomesfaen, and *s*-metolachlor systems for glufosinate-resistant cotton residual weed management. *Weed Tech.* 23: 391-397.

Graham, C.T., J.N. Jenkins, J.C. McCarty Jr. 1995. Performance of GAUCHO™ seed treatment insecticide against early season cotton insect pests. p. 917-918. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Greene, Jeremy K., C. Capps, B. Myers, J. Reed. 2002. Control Options for Thrips in Southeast Arkansas. *Summaries of Arkansas Cotton Research*. pp. 254-258

Hake, S. J., K. D. Hake, and T. A. Kerby. 1996. Preharvest/harvest decisions. Pages 73–81 in S. J. Hake, ed. Cotton Production Manual. *Division of.Agricultural.Natural Resources* Publ. 3352.

Heap, I. 2008. The International Survey of Herbicide Resistant Weeds. http://www.weedscience.org . Accessed 3 Dec. 2014.

Kendig, J.A., R.L. Nichols, G.A. Ohmes. 2007. Tolerance of Cotton (*Gossypium hirsutum*) Seedlings to Preemergence and Postemergence Herbicides with Four Modes of Action. *Plant Management Network*. http://www.plantmanagementnetwork.org/pub/php/research/2007/cotton Accessed 28 August 2014.

Layton, B. and J.T. Reed. 2002. Biology & Control of Thrips on Seedling Cotton. *Mississippi State University Extension Service*. Publication 2302.

Lingenfelter, D.D., N.L. Hartwig. 2007. Introduction to Weeds and Herbicides. *Pennsylvania State University*. Publication UC175

Maienfisch, P., M. Angst, F. Brandl, W. Fischer, D. Hofer, H. Kayser, W. Kobel, A. Rindlisbacher, R. Senn, A. Steinimann, and H. Widmer. 2001. Chemistry and Biology of thiamethoxam: a second generation neonicotinoid. *Pest Mgmt. Sci.* 57: 906- 913.

Main, C.L., J.C. Faircloth, L.E. Steckel, A.S. Culpepper, A.C. York. 2012. Cotton tolerance to fomesafen applied preemergence. *J. Cot. Sci.*16:. 80-87.

Reed, J.T., and C.S. Jackson. 2002. Thrips on Mississippi Seedling Cotton: Pest overview and 15-Year Summary of Pesticide Evaluation. *Mississippi State University Extension Service*. Bulletin 1124.

Reisig, D., D.A. Herbert, S. Malone. 2012. Impact of Neonicotinoid Seed Treatments on Thrips (Thysanoptera: Thripidae) and Soybean Yield in Virginia and North Carolina. *J. Econ. Entomol.* 105(3): 884-889.

Roberts, B.A. and E.A. Rechel. 1996. Effects of early season thrips feeding on root development, leaf area, and yield. p. 939-941. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Rummel, D., G. Baker, and J. Hatfield. 1988. Interaction of weather and thrips injury during the early cotton growing season. p. 299-301. *In* Proc. Beltwide Cotton Prod. Res. Conf., New Orleans, LA. 3-8 Jan. 1988. Natl. Cotton Counc. Am., Memphis, TN.

Stewart, S., S.D. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R. Jackson, D. Kerns, B.R. Leonard, G. Lorenz, S. Micinski, D. Reisig, P. Roberts, G. Stude Baker, K. Tindall, M. Toews. 2013. Survey of Thrips Species Infesting Cotton across the Southern U.S. Cotton Belt. *J. Cot. Sci.*17(2): 1-7

Webster, T.M. 2014. Weed survey- southern states: broadleaf crops subsection. *In* Proc. S. Weed Sci. (67): 282-293

Williams, M.R. 2013. Cotton Insect Losses 2012. p. 546-586. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 7-10 Jan. 2013. Natl. Cotton Counc. Am., Memphis, TN.

CHAPTER IV

EVALUATION OF SOIL TEXTURE AND PRE HERBICIDE ON COTTON GROWTH AND DEVELOPMENT

Abstract

Early season cotton growth is naturally slow which can be further reduced by herbicide injury. Preemergence herbicide use can result in early season cotton injury especially under unfavorable environmental condition. Greenhouse studies were conducted in 2014 to determine the impact of PRE herbicides and soil texture on early season cotton growth and development. Deltapine 0912 B2RF seed (treated with metalaxyl [0.014 mg ai/seed] + pyraclostrobin [0.04 mg ai/seed] + ipconazole[0.002 mg ai/seed] + fluxapyroxad [0.018 mg ai/seed] + thiamethoxam [0.375 mg ai/seed] + abamectin [0.15 mg ai/seed]) were planted in a Bosket very fine sandy loam soil (49.7% silt, 27.8% sand, 22.7% clay, and 1.9% organic matter) and a Griffith silty clay soil (56.2 % clay, 29.2 % silt, 14.6 % sand, and 3.7% organic matter). Preemergence herbicides included fluometuron, diuron, fomesafen, *S*-metolachlor, and *S*-metolachlor + fluometuron 1.12, 1.12, 0.28, 1.07, and 1.07 + 1.12 kg ai^{-1}, respectively, as well as an untreated check. At three weeks after planting (WAP), cotton grown in sandy loam soil had greater leaf counts than cotton grown in silty clay soil regardless of PRE herbicide applied. Additionally, cotton grown in sandy loam soils were taller than cotton grown in silty clay soils at two, three, and four WAP. Cotton height reductions were observed

when *S*-metolachlor+ fluomeutron was applied PRE compared to the untreated check. Cotton treated with fomesafen and *S*-metolachlor + fluometuron had 0.5 to 5.9% biomass reductions when compared to the untreated check.

Introduction

Glyphosate-resistant (GR) cotton (*Gossypium hirsutum* L.) cultivars are grown on 97% of the cotton hectares in the southern United States (USDA/AMS 2014). Glyphosate has been used heavily on by cotton growers for effective and efficient weed control. In conjunction growers transitioned away from soil-applied residual herbicides (Culpepper et al. 2010). Consequently, the development and spread of GR populations of common ragweed (*Ambrosia artemisiifolia* L.), giant ragweed (*Ambrosia trifida* L.), Palmer amaranth (*Amaranthus palmeri* [S. Wats.]), spiny amaranth (*Amaranthus spinosus* L.), tall waterhemp (*Amaranthus tubrculatus* [Moq.]), johnsongrass (*Sorghum halepense* L.), goosegrass (*Eleusine indica* L.), Italian ryegrass (*Lolium perenne ssp. multiflorum* L.), and horseweed (*Conyza canadensis* [L] Cronq.) has led to renewed interest in PRE residual herbicides (Brewer and Oliver, 2009; Culpepper et al. 2006; Heap, 2007; 2010; 2012; Main et al. 2004; Molin and Nandula, 2010 Norsworthy et al. 2010) .

Glyphosate-resistant Palmer amaranth is the leading weed management issue for cotton producers across the U.S. Cotton Belt (Culpepper et al. 2010; Culpepper and Steckel, 2010; Webster 2014). Glyphosate-resistant Palmer amaranth along with other troublesome weeds has necessitated increased use of preemergence (PRE) residual herbicides to achieve adequate weed control (Culpepper 2009). Residual herbicides have longer half- lives in the soil and provide extended weed control needed due to slow early season growth of cotton (Buchanan 1992; Colquhoun 2006). The choice of PRE herbicide is one of the most important decisions made during a growing season. Cotton, which has slow early season growth and development, usually requires up to eight weeks of early season weed control to out-compete weeds for sunlight and achieve maximum yields (Buchanan and Burns, 1970; Buchanan 1992). Preemergence herbicide applications that are made before or after planting are essential in ensuring cotton has a competitive advantage over weeds (Lingenfelter and Hartwig 2007; Ferrell et al. 2012).

The presence of troublesome GR weeds, specifically Palmer amaranth, can disrupt development and yield of all agronomic crops; however, cotton is one of the more affected crops (Culpepper et al. 2010). Everman et al. (2009) observed yield losses when weed management programs lacked PRE herbicides in cotton. Therefore, programs that depend on post-emergence (POST) herbicides only may result in a significant yield loss due to early season weed competition (Askew and Wilcut 1999; Everman et al. 2009). Successful management of GR weeds require use of PRE herbicides followed by a timely POST to maximize cotton yields (Dodds et al. 2005; Scroggs et al. 2007; Culpepper et al. 2010).

Early season cotton growth can be delayed by factors such as cool temperatures, high soil moisture, insects, nutrient deficiencies, and seedling diseases (Chaudhry and Guitchounts 2003). Additionally, these factors can exacerbate symptoms observed from herbicide injury (Lingenfelter 2007). While preemergence herbicides are advantageous for maintaining weed control, they also have potential to injure and delay early season growth of cotton (Kendig et al. 2007). Cotton injury from PRE herbicides has been previously reported (Main et al. 2012; Kendig et al. 2007).

Commonly used herbicides such as fomesafen, *S*- metolachlor, diuron, and fluometruon are labeled for use PRE in cotton but can cause injury if not used according to label directions or environmental conditions are not favorable (Anonymous 2014a; 2014b; 2014c; 2014d). Price et al. (2004) found that fomesafen applied PRE proceeding a significant rainfall can result in increased absorption through seedling root tissue during emergence which can cause significant foliar necrosis. In North Carolina, fomesafen applied PRE resulted in 21 to 24% visual necrosis on cotton with yields reduced up to 25% (Main et al. 2012). Depending on soil texture and recommended application rates, *S*-metolachlor and fluometuron can cause injury to emerging cotton (Kendig et al. 2007). In soybeans (*Glycine max* L.), previous research indicates PRE applied protoporphyrinogen oxidase (PPO) inhibiting herbicides, such as flumioxazin and sulfentrazone, caused injury when soil pH rose from 5.5 to 7.5 and soybeans were grown under wet, low organic matter soil conditions (Reiling et al. 2006; Taylor-Lovell et al. 2001). Previous research suggests that soil texture when PRE herbicides are utilized can impact early crop development (Westra et al. 2014; Gannon et al. 2014). However, research is lacking on how different soil textures combined with commonly used PRE herbicides affect early season cotton growth and development. With the extensive use of PRE herbicides in cotton weed management programs, it is critical to determine cotton response to commonly applied PRE herbicides and how cotton injury may be affected by soil texture.

Materials and Methods

A greenhouse experiment was conducted in 2014 to determine the effect of PRE herbicide and soil texture on early cotton growth and development. Experiments were conducted in the greenhouse complex at the R. R. Foil Plant Science Research Center near Starkville, MS. Deltapine 0912 B2RF (treated with metalaxyl [0.014 mg ai/seed] + pyraclostrobin [0.04 mg ai/seed] + ipconazole[0.002 mg ai/seed] + fluxapyroxad [0.018 mg ai/seed] + thiamethoxam [0.375 mg ai/seed] + abamectin [0.15 mg ai/seed]) cotton (Monsanto Company, St. Louis, MO) seed were planted in two distinct soil textures collected from on-farm locations in Mississippi. Samples for each soil type were analyzed for nutrient analysis and soil texture classification prior to beginning experiments (A&L Laboratories, Memphis, TN). A Bosket very fine sandy loam soil containing 49.7% silt, 27.8% sand, and 22.7% clay was collected from Stoneville, MS (33°25’22.1”N 90°54’00.3”W). A Griffith silty clay soil was collected from Brooksville, MS (33°15’26.2”N 88°32’29.6”W) and contained 56.2 % clay, 29.2 % silt, and 14.6 % sand.

Pots which were 17 cm in diameter and 20 cm deep were utilized in this experiment. Each pot had a 20 cm diameter liner beneath to assist each pot with sub-irrigation. Soils were dried and sieved with a 9.5 mm sieve prior to initiation of the experiment. All pots were lined with Greenscapes® premium landscape fabric (Greenscapes, Calhoun, Georgia) for soil containment. Each pot contained 2600 g of soil. Soil within the pots was fertilized with 0.74 ml of Miracle-Gro® Liquafeed® (9-4-9) (The Scotts Company, LLC, Marysville, Ohio). Fertilizer application rate supplied 67 kg N ha^{-1}, 34 kg P_2O_5 ha^{-1}, and 67 kg K_2O ha^{-1}. Fertilizer was applied in 25 ml of water. Subsequently, three seeds from the selected cultivar were hand planted approximately 1.9 cm deep into the soil of each pot.

A repeated measures design with a factorial arrangement of treatments replicated ten times was utilized for this experiment and the experiment was repeated twice in time.

Factor A consisted of soil texture and included a Bosket very fine sandy loam and a Griffith silty clay. Factor B consisted of PRE herbicides and included fluometuron (Cotoran 4L- Makhteshim Agan of North America, Raleigh, NC), *S*-metolachlor (Dual Magnum- Synegenta Crop Protection, Greensboro, NC), diuron (Direx 4L- Makhteshim Agan of North America, Raleigh, NC), fomesafen (Reflex- Synegenta Crop Protection, Greensboro, NC), a combination of *S*-metolachlor + fluometuron at 1.12, 1.07, 1.12, 0.28, and 1.07+ 1.12 kg ai ha^{-1}, respectively, and an untreated check. Factor C represented weeks after planting and consisted of five levels which were one, two, three, four, and five weeks after planting. Preemergence herbicides were applied within 3 hours after planting using a CO_2 - pressurized spray chamber. The spray chamber was calibrated to deliver 140 L ha^{-1}. Tips used were 80015E at 207 kPa. After herbicide application, all pots were irrigated with 1.27 cm of water from a rainfall simulator to activate the residual herbicides (Stickler et al. 1969). Pots were then placed in the greenhouse with temperatures ranging from 24^0 to 35^0C to ensure optimal growing conditions for cotton (Gipson 1986). Propagation mats were used beneath all pots to ensure optimum soil temperature and were set at 29^0C for the duration of the experiment. Additionally, pots were sub-irrigated for the remainder of the experiment. Weeds in untreated and treated pots were hand removed for the duration of the experiment.

Evaluation of cotton response included growth stage and height measurements (in cm) 7, 14, 21, 28, and 35 days after planting. At 36 DAP, cotton plants in each pot were harvested by cutting the plant at the soil surface and immediately weighed to obtain fresh biomass weight. Afterwards, all plant samples were placed into air forced dryers set at 70^0C for 72 hours. After drying, dry weights for plants within each pot were determined.

Data were subjected to analysis of variance using the PROC MIXED procedure of SAS v. 9.3 (SAS institute; Cary, NC). Means were separated using Fisher's Protected LSD ($\alpha \leq 0.05$). Degrees of freedom were calculated using the Kenward-Roger method.

Results and Discussion

No interactions were observed between soil texture, PRE herbicide, and time or PRE herbicide and time for cotton height (Table 4.2). A significant interaction between soil texture and time was observed for cotton height (Table 4.2). Cotton heights from one to five weeks after planting ranged from 4 to 25 cm. At one and five weeks after planting no differences in height were observed between cotton grown in sandy loam or silty clay soil (Table 4.4). However, at two, three, and four weeks after planting cotton grown in sandy loam soil was significantly taller than cotton grown in silty clay soil.

Cotton growth stage was not significantly affected by an interaction between soil texture, PRE herbicide, and weeks after planting or an interaction between PRE herbicide and weeks after planting (Table 4.2). PRE herbicide had an impact on growth stage (Table 4.2).Cotton treated with fomesafen, fluometuron, and diuron had more true leaves than cotton treated with *S*- metolachlor + fluometuron (data not shown). Additionally, cotton treated with *S*-metolachlor + fluometuron had similar numbers of true leaves compared to cotton treated with *S*- metolachlor and the untreated check. In addition, an interaction between soil texture and time was significant (Table 4.2). Cotton growth stages ranged from cotyledon to five true leaves for cotton planted in sandy loam soils and silty clay soils (Table 4.4). No differences in growth stage were observed, at one, two, and four weeks after planting. Three weeks after planting cotton grown in sandy loam soil had more true leaves than cotton grown in silty clay soil. However, at five weeks after planting cotton grown in silty clay soil had more true leaves than cotton grown in sandy loam soil.

Soil texture and PRE herbicide application both significantly impacted fresh biomass (Table 4.2). Fresh biomass ranged from 3.8 to 4.6 g per plant at five weeks after planting. Cotton grown in silty clay soil had significantly less fresh weight biomass than cotton grown in sandy loam soil (Table 4.3). Cotton treated with diuron had greater fresh weight than cotton treated with fomesafen or *S*-metolachlor + fluometuron (Table 4.3). However, fresh weights of cotton that was treated with diuron PRE was not different then fresh weight of cotton treated with fluometuron, *S*-metolachlor, *S*-metolachlor+ fluometuron or the untreated check at five weeks after planting. Results are similar to Askew et al. (2002) who reported biomass reductions when residual PRE herbicides were applied to cotton. Dry biomass was not affected by PRE herbicide; however, soil texture effects were significant (Table 4.2). Cotton dry biomass weight ranged from 1.2 to 1.6 g per plant. Cotton grown in sandy loam soil had greater dry biomass than cotton grown in silty clay soil (Table 4.3).

In conclusion, cotton grown in sandy loam soils was more vigorous regardless of herbicide. However, cotton treated with fomesafen had less biomass than cotton treated with diuron and fluometuron when compared to the untreated check. These data highlight the importance of abiding by label restrictions for PRE herbicide use. Growers should understand that herbicides, such as fomesafen, can potentially cause delayed early season development. Variable environmental conditions such as soil texture of a field and choice of herbicide can result in vigor reductions and potential yield loss. Growers should acknowledge their environment by managing controllable factors to prevent early season growth reductions. Preemergence herbicide selection should be based on soil texture, efficacy, grower preference, and cost.

Table 4.1 Soil texture, collection site; percent clay, sand, silt, and organic matter.

Soil texture	Collection Site	Clay	Sand	Silt	Organic Matter
		------------------------	------------ %	------------	------------------------
Bosket very fine sandy loam	Stoneville, Mississippi	22.7	27.8	49.7	1.9
Griffith silty clay	Brooksville, Mississippi	56.2	14.6	29.2	3.7

Table 4.2 Analysis of variance p-values for plant height, growth stage, fresh biomass, and dry biomass as affected by soil texture, PRE herbicide, and time.

Source	Degrees of Freedom	Plant Height*	Growth Stage*	Fresh Biomass**	Dry Biomass**
Soil Texture	1	0.0033	0.2308	<0.0001	<0.0001
PRE Herbicide	5	0.0533	0.0169	0.0202	0.0517
Soil Texture x PRE Herbicide	5	0.5869	0.3823	0.1465	0.4550
Time	4	<0.0001	<0.0001	--	--
Soil Texture x Time	4	0.0014	<0.0001	--	--
PRE Herbicide x Time	20	0.6068	0.0953	--	--
Soil Texture x PRE Herbicide x Time	20	0.9781	0.6473	--	--

*Data recorded weekly.
**Terminal data.

Table 4.3 Cotton fresh and dry biomass as affected by soil texture and PRE herbicide independently [abc].

Soil Texture	PRE Herbicide	Fresh Biomass	Dry Biomass
		— g —	— g —
Sandy loam	--	13.9 a	4.7 a
Silty clay	--	11.5 b	3.7 b
--	Diuron	13.7 a	--
--	Fluometuron	13.2 ab	--
--	Fomesafen	11.9 c	--
--	*S*- metolachlor	12.8 abc	--
--	*S*- metolachlor + Fluometuron	12.2 bc	--
--	Untreated	12.6 abc	--

[a]Data for soil textures were pooled over PRE herbicide and time as no interactions were observed.
[b]Data for PRE herbicide were pooled over soil textures and time as no interactions were observed.
[c]Means within a column followed by the same letter were not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

Table 4.4 Growth stage and plant height as affected by an interaction between soil texture and time [ac].

Soil Texture	Time [b]	Growth Stage	Plant Height
		— # True Leaves —	— cm —
Sandy loam	1	1.0 g	4.4 h
	2	2.8 f	13.2 f
	3	4.5 d	18.7 d
	4	5.0 c	23.1 b
	5	5.5 b	24.5 a
Silty Clay	1	1.0 g	4.5 h
	2	2.7 f	11.1 g
	3	4.0 e	16.1 e
	4	5.0 c	21.1 c
	5	5.8 a	24.3 ab

[a]Data were pooled over PRE herbicides as no interactions were observed.
[b]Numbers within a column represent the number of weeks after planting.
[c]Means within a column followed by the same letter were not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

References

Anonymous. 2014a. Reflex herbicide label. Available at http://www.cdms.net. (Verified 9 Sept. 2014).

Anonymous. 2014b. Cotoran herbicide label. Available at http://www.cdms.net. (Verified 9 Sept. 2014).

Anonymous. 2014c. Dual Magnum herbicide label. Available at http://www.cdms.net. (Verified 9 Sept. 2014).

Anonymous. 2014d. Direx herbicide label. Available at http://www.cdms.net. (Verified 9 Sept. 2014).

Askew, S.D. and J.W. Wilcut. 1999. Cost of weed management with herbicide programs in glyphosate-resistant cotton (*Gossypium hirsutum*). *Weed Tech.* (13): 308-314.

Askew, S.D., J.W. Wilcut, and J.R. Cranmer. 2002. Cotton (*Gossypium hirsutum*) and Weed Response to FLuMioxazin Applied Preplant and Postemergence Directed. *Weed Tech.* 16(1): 184-190.

Brewer, C.E., and L.R. Oliver. 2009. Confirmation and resistance mechanisms in glyphosate-resistant common ragweed (*Ambrosia artemisiifolia*) in Arkansas. *Weed Sci.* (57): 567-573.

Buchanan, G.A. 1992. Trends in Weed Control Methods. *In* McWhorter, G.M., J.R. Abernathy (ed). Weeds of Cotton: Characterization and Control. p. 47-72.

Buchanan, G.A., and Burns E.R. 1970. Influence of weed competition on cotton. *Weed Sci.* (18): 149-154.

Chaudhry, M.R., A. Guitchounts. 2003. Cotton Facts. *Common Fund for Commodities Technical paper No. 25*: pp. 35-83

Colquhoun, J. 2006. Herbicide persistence and carryover. University of Wisconsin-System Board of Regents and University of Wisconsin- Extension, Cooperative Extension. Publication A3819.

Culpepper, A.S. 2009. Herbicide resistance impacting cotton production. p. 93. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 2009. Natl. Cotton Counc. Am., Memphis, TN.

Culpepper, A.S., and L.E. Steckel. 2010. Value of Transgenic Crops- Weed Management. p. 6-7. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 5-7 Jan. 2010. Natl. Cotton Counc. Am., Memphis, TN.

Culpepper, A.S., T.L. Grey, W.K. Vencill, J.M. Kichler, T.M. Wedster, S.M. Brown, A.C. York, J.W. Davis, and W.W. Hanna. 2006. Glyphosate- resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. *Weed Sci.* (54): 620-626.

Culpepper, A.S., T.M Webster, L.M. Sosnoskie, A.C. York. 2010. Glyphosate- resistant Palmer amaranth in the United States. *Glyphosate Resistance in Crops and Weeds: History, Development, and Management*. pp. 195- 212.

Dodds, D.M., D.B. Reynolds, J.J. Walton, M.T. Kirkpatrick. 2005. The use of residual herbicides in conjunction with early postemergence applications od glyphosate or glufosinate in transgenic weed control programs. p.2930-2931. *In* Proc. Beltwide Cotton Conf., New Orleans, LA, 4-7 Jan. 2005. Natl. Cotton Counc. Am., Memphis, TN.

Everman, W.J., S.B. Clewis, A.C. York, J.W. WIlcut. 2009. Weed control and yield with flumioxazin, fomesfaen, and *s*-metolachlor systems for glufosinate-resistant cotton residual weed management. *Weed Tech.* (23): 391-397.

Ferrell, J.A., G.E. MacDonald, R.Leon. 2012. Weed Management in Cotton. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication SS-AGR-04

Gannon, T.W., A.C, Hixson, K.E. Keller, J.B. Weber, S.Z. Knezevic, and F.H. Yelverton. 2014. Soil Properties Influence Saflufenacil Phytotoxicity. *Weed Tech.* 62(4): 657-663.

Gipson, J.R. 1986. Temperature effects on growth, development, and fiber properties. *Cotton Physiology, The Cotton Foundation*. pp. 47-56.

Heap, I. 2007. The International Survey of Resistant Weeds [Online]. Available at http://www.weedscience.org. (verified 3 September 2014).

Heap, I. 2010. The International Survey of Resistant Weeds [Online]. Available at http://www.weedscience.org. (verified 3 September 2014).

Heap, I. 2012. The International Survey of Resistant Weeds [Online]. Available at http://www.weedscience.org. (verified 3 September 2014).

Kendig, J.A., R.L. Nichols, G.A. Ohmes. 2007. Tolerance of Cotton (*Gossypium hirsutum*) Seedlings to Preemergence and Postemergence Herbicides with Four Modes of Action. *Plant Management Network*. http://www.plantmanagementnetwork.org/pub/php/research/2007/cotton/ Accessed 28 August 2014.

Lingenfelter, D.D., N.L. Hartwig. 2007. Introduction to Weeds and Herbicides. *Pennsylvania State University*. Publication UC175

Main, C.L., J.C. Faircloth, L.E. Steckel, A.S. Culpepper, A.C. York. 2012. Cotton tolerance to fomesafen applied preemergence. *J. Cot. Sci.*(16): 80-87.

Main, C.L., T.C. Mueller, R.M. Hayes, J.B. Wilkerson. 2004. Response of selected horseweed (*Conyza Canadensis* (L.) Cronq.) populations to glyphosate. *J. of Agric., Food, and Chem.* (52): 879-883.

Molin, W. and V. Nandula. 2010. The International Survey of Resistant Weeds [Online]. Available at http://www.weedscience.org. (verified 3 September 2014).

Norsworthy, J.K., R. Jha, L.E. Steckel, and R.C. Scott. 2010. Confirmation and control of glyphosate- resistant giant ragweed (*Ambrosia trifida*) in Tennessee. *Weed Tech.* (24): 64-70.

Price, A.J., J.W. Wilcut, and J.R. Cranmer. 2004. Physiological behavior of root-absorbed flumioxazin peanut, ivyleaf morningglory (*Ipomoea herderacea*), and sicklepod (*Senna obtusifolia*). *Weed Sci.* (52): 718-724.

Reiling, K.R., F.W. Simmions, D.E. Reichers, and L.E. Steckel. 2006. Application timing on soil pH effects on sulfentrazone phytotoxicity to two soybean (*Glycine max* (L) Merr.) cultivars. *J. Crop Prot.* (25): 230-234.

Scroggs, D.M., D.K. Miller, J.L. Grffin, L.E. Steckel, D.C. Blouin, A.M. Stewart, and P.R. Vidrine. 2007. Reduced-input Post Emergence Weed Control with Glyphosate and Residual Herbicides in Second-Geneartion Glyphosate-Resistant Cotton. *Weed Tech.* 21(4):997-1001.

Stickler, R. L., E. L. Knake, and T. D. Hinesly. 1969. Soil moisture and effectiveness of preemergence herbicides. *Weed Sci.* p.257-259.

Taylor- Lovell, S., L.M. Wax, and R. Nelson. 2001. Phytotoxic response and yield of soybean (*Glycine max*) varieties treated with sulfentrazone or flumioxazin. *Weed Tech.* (15): 95- 102.

USDA/AMS. 2014. Cotton Varieties Planted 2014 Crop. Agricultural Marketing Service-Cotton Program. Accessed 24 March 2015. http://www.ams.usda.gov.

Webster, T.M. 2014. Weed survey- southern states: broadleaf crops subsection. *In* Proc. S. Weed Sci. (67): 282-293

Westra, E.P., D.L. Shaner, P.H. Westra, and P.L. Chapman. 2014. Dissipation and Leaching of Pyroxasulfone and S- metolachlor. *Weed Tech.* 28(1)